BRE TRUST REVIEW 2011

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The mission of BRE Trust is 'Through education and research to promote and support excellence and innovation in the built environment for the benefit of all'. Through its research programmes the Trust aims to achieve:

- a higher quality built environment
- built facilities that offer improved functionality and value for money
- a more efficient and sustainable construction sector, with
- a higher level of innovative practice.

A further aim of BRE Trust is to stimulate debate on challenges and opportunities in the built environment.

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FOREWORD

Ten years ago in 2002 BRE Trust became a registered charity. This was a crucially important step for BRE and the built environment and it is worth reflecting on its significance and what has been achieved in the intervening ten years.

Being owned by a charity ensured that the BRE operating company retained its independence and authority as a world-respected research organisation, but ten years ago it also freed the BRE Trust (then the Foundation for the Built Environment) from the constraints of being a scientific research organisation and enabled it to focus on research into the built environment. Consequently, BRE Trust is the largest UK research and education charity for the built environment.

The continued commercial success of the BRE companies since privatisation in 1997 has allowed them to deliver generous Gift Aid to the BRE Trust. This has enabled it to support a wide range of education, research and carbon reduction projects, many of which have informed UK Government strategy and regulation on energy efficiency, sustainability, CO_2 reduction and fire safety, both in the UK and other parts of the world.

During this period, the Trust has supported over 70 PhD students, five chairs at the BRE University Centres of Excellence and over 220 research projects. It has produced over 150 new publications in the last three years alone and formed successful research collaborations with the National House-Building Council (NHBC), Waste & Resources Action Programme (WRAP) and Cornwall Council, and sponsored a large number of conferences and school events.

Many of the research projects attract research funding from other sources. The BRE University Centres of Excellence have gone from strength to strength and between them currently support 110 PhDs, 39 full-time equivalent staff and 25 research associates, having secured over £25m of other funding.

In the financial year 2010/11, due entirely to the successful performance of BRE in a difficult economic environment, BRE Trust has had sufficient funds to continue meeting its objectives. The Gift Aid delivered in the year to the Trust was £2.904m compared with £2.341m in 2009/10. The total BRE Trust expenditure on research in 2010/11 was £2.93m compared with £2.88m in 2009/10, of which £2.08m was spent on its responsive mode programme and £538k on its successful three-year thematic research programme on low-impact materials products and processes. Grants to University Centres of Excellence and the PhD studentships increased to £848k in the year.

The Trust acknowledges the importance and value to the built environment of BRE's highly influential publications: *Digests*, *Information Papers*, guides and reports. In the financial year 2010/11, the Trust donated £529k to the publications programme.

There are many up-and-coming challenges facing those involved with the built environment: the problems of an aging population and increased demands on health care in the home, the energy-inefficient buildings that we live and work in, the aging infrastructure that we plug into for light, heat and power, none of which can be entirely solved by new buildings or even by new ways of building. Information technology, high-speed broadband and remote sensors are going to give utility suppliers the ability to manipulate our appliances remotely to reduce energy consumption and give doctors the ability to monitor our heartbeats remotely. This will have a profound influence on the way we build and refurbish our environment and form the communities of the future. These ideas need rigorous and robust science behind them and BRE Trust is currently approving a new thematic research programme 'Future Cities' to ensure that the appropriate information, knowledge and tools are available.

This *Review* provides an opportunity for BRE Trust to share summaries of the recently completed work that it has funded through its various programmes of research and education, including the thematic and responsive research programmes and the publications programme.

In conclusion and on behalf of the Trustees, I would like to thank BRE, BRE Global, the five BRE University Centres of Excellence, the PhD students, the BRE Trust partners and other organisations who have contributed to this *Review* by highlighting and summarising their important research activities and publications.

Sir Neville Simms FREng
Chairman
BRE Trust

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Cont'd . . .

BRE TRUST HIGHLIGHTS OF 2011

INNOVATION PARKS

BRE Trust is supporting research to assist with the development of an Innovation Park in Beijing

Following the visits to the Innovation Park at BRE's Watford site of the Prime Minister David Cameron in 2010 and then the Chinese Vice Premier Li-Keqiang in 2011, BRE has been invited to collaborate with partners in China, Brazil, the US and Canada to establish a global network of Innovation Parks.

Accords were signed by CEO of BRE, Peter Bonfield:

- with China in June 2011 in the presence of UK Prime Minster, David Cameron, and Chinese Premier, Wen Jiabao
- with Brazil in August 2011 in the presence of the Brazilian Minister for Science and Technology, Aloizio Mercadante, and President of Brazil, Dilma Rousseff.

BRE Trust is supporting research to develop an Innovation Park on a 450 000 m^2 Green Building Park in Beijing. The park will feature UK design, materials and products for sustainable homes, and the research will map the differences and similarities of BREEAM and the current Three Star Building rating system used in China. It will result in the production of an environmental assessment tool that will assist Chinese markets to adapt the use of BREEAM where appropriate and will help China to develop business in the UK.

The concept of Innovation Parks was created by BRE in 2005 with the aim of using full-scale buildings to demonstrate the pioneering ideas of architects, developers and manufacturers before they are widely adopted in the community. BRE Trust has supported research into the performance in practice of some of these ideas through opinion surveys, research and publications (Box 1).

The most recent project to be completed on the Innovation Park at BRE's Watford site is the Prince's House constructed by the Prince's Foundation for Building Community to demonstrate easy-to-build, low-tech sustainable housebuilding. The house was launched by Housing Minister, Grant Shapps, in June 2011.

Signing of accords by BRE's CEO, Peter Bonfield, to develop Innovation Parks in China (top) and Brazil (bottom)

The Prince's House on the Innovation Park at BRE's Watford site (top) launched by Housing Minister, Grant Shapps (bottom)

Innovation Parks are also being developed in partnership with BRE in:

- Ravenscraig, Scotland
- Ontario, Canada
- Portland, USA.

For more information on these innovation parks and the BRE Innovation Network, visit www.bre.co.uk/page.jsp?id=634 or contact innovationpark@bre.co.uk or call 0845 2232 966.

***Box 1:* Publications featuring research conducted on the Innovation Park at BRE's Watford site**

Ref. no.	Title
FB 20	Complying with The Code for Sustainable Homes: Lessons learnt on the BRE Innovation Park
BR 506	Smart home systems and The Code for Sustainable Homes: A BRE guide
IP 9/08	Applying The Code for Sustainable Homes on the BRE Innovation Park (4 Parts; re-published in 2009 as BRE Trust Report FB 20)
IP 3/09	Lessons learned from the Barratt Green House: Delivering a zero carbon home using innovative concrete systems
IP 2/10	Ground source heat pumps
IP 6/10	A guide to Greenprint: understanding the benefits for sustainable masterplanning
IP 14/10	Consumer feedback on low-carbon housing
IP 20/10	Delivering a successful demonstration project

BRE TRUST RESEARCH CONFERENCE

A new format for the BRE Trust Research Conference proved to be a great success

To coincide with the 90th Anniversary of BRE, the 2011 BRE Trust Research Conference chaired by Professor John Burland was held on the morning of 24 May 2011 at the Saatchi Gallery in London, followed in the afternoon by BRE's own annual conference. Many of the invited audience opted to attend both conferences and the Research Conference was attended by 150 delegates, a larger audience than ever before.

It was the first time that the BRE Trust Research Conference was held as a mainstream event organised alongside the BRE Annual Conference and it was an opportunity for those responsible for standards, legislation and regulation to hear first-hand reports of BRE Trust-funded research. The rigorous research plays a key role in developing understanding of fire and security issues and the innovative materials, products and processes that are being introduced into the built environment to reduce environmental impacts.

Researchers from BRE joined PhD students funded by the Trust to speak on the following topics:

- achieving level 4 of the Code for Sustainable Homes with fabric solutions only
- renewable construction materials
- low-impact shop fitting
- advanced controls for energy systems
- IMPACT – whole building life-cycle analysis
- monitoring occupant behaviour in sustainable homes
- evacuation of dependent people from buildings.

As the feedback to the new format was so positive, the same format will be adopted for the 2012 BRE Trust Research Conference which will be held on the morning of 15 May 2012 at the British Museum followed in the afternoon by the BRE Conference (contact Amanda Brackey for further information).

BRE UNIVERSITY CENTRES OF EXCELLENCE

A collaboration of industry and academia – BRE Trust, BRE and five BRE University Centres of Excellence – to bring rigorous science to solve the challenges facing the built environment

During 2011, BRE Trust provided grants to support five University Chairs at the BRE University Centres of Excellence at Bath, Cardiff, Edinburgh and Strathclyde (see Table 1 for details) and contributed to the funding of 30 PhD students carrying out important leading-edge research to improve our understanding of the built environment and how the user interacts with it.

This is a collaborative arrangement to encourage a wide range of specialisms and skills to be brought to bear on the problems facing the built environment in response to global warming and dwindling non-renewable resources. Details of the research can be found in the main body of this *Review* starting on page 13.

The BRE University Centres of Excellence met twice during 2011 to report on progress and discuss further opportunities for collaborative research. The centres themselves have been very successful in bidding for additional funding for research from government and industrial partners.

The BRE Trust Research Committee (chaired by Professor John Burland) has been pleased with the significant development in collaborative working at all the centres over the past year. The Committee commented that:
'the size of centres and the growth and impact of projects being won and delivered confirms a real commitment on the part of the Chairs and their own organisations.'

The outcome of this partnership between academia and industry (of blue sky and applied research) is the information, knowledge and tools needed to meet the challenges we face for the future upkeep and development of the built environment and the health and wellbeing of people who use it (see Forewords by Sir Neville Simms and Professor John Burland).

ENGINEERING AND PHYSICAL SCIENCES RESEARCH COUNCIL (EPSRC) CASE AWARDS

BRE receives two EPSRC CASE awards

Following meetings between BRE and EPSRC over the past year, EPSRC has awarded BRE two CASE awards. This recognises the importance of the research that BRE and its academic partners are undertaking.

Table 1: **BRE University Centres of Excellence**

Organisation	No. of PhD students and full-time staff	Total funding secured since start	Value of bids currently in preparation or being reviewed	Active research areas
University of Bath BRE Centre for Innovative Construction Materials *Professor Peter Walker*	43 PhDs 15 staff 11 research associates/ post-doctoral staff/ technicians	£5.1m	£3.2m	Advanced and natural composites, low-carbon materials, timber, concrete, steel and masonry
University of Strathclyde BRE Centre for Energy Utilisation *Professor John Counsell*	13 PhDs 7 staff 5 research associates	£2.2m	£3.1m+	Dynamic simulation, building controls, energy demand management, energy efficiency and carbon reduction, low-carbon offices, intelligent controls, energy reduction in homes
University of Edinburgh BRE Centre for Fire Safety Engineering *Professor José Torero*	9 PhDs 9 staff 6 research associates	£9.15m	£2m+	Modelling, design, materials, structures and fire protection
Cardiff University BRE Centre for Sustainable Design of the Built Environment *Professor Chris Tweed*	10 PhDs 1 staff 1 research associate	£7.9m	£22m+	Design for sustainable refurbishment, occupancy behaviour related to energy efficiency, neighbourhood dashboards
Cardiff University BRE Centre for Sustainable Engineering *Professor Yacine Rezgui*	35 PhDs 7 staff 2 research associates	£1.4m	£1.85m	Resilience of the built environment, assisted living/ageing, renewable energy for the domestic sector, low-carbon design
Total	**110 PhDs** **39 staff** **25 research associates**	**£25.75m**	**£32m+**	

Professor Chris Tweed, Cardiff University, and Professor Peter Walker, University of Bath, submitted successful applications and the PhD EPSRC CASE award student at Cardiff University has already started a research project on whole life-cycle costing in retrofit and refurbishment.

PhD AWARDS

Lloyd's Science of Risk Prizes in the category of Biological/Technological risk won by PhD students from the BRE University Centre of Excellence for Fire Safety Engineering at the University of Edinburgh

Dr Angus Law and co-authors J Stern-Gottfried, M Gillie and G Rein were awarded the prize for the paper on the influence of travelling fires on a concrete frame. The Science of Risk Prize was launched by Lloyd's to stimulate cutting-edge research into emerging risks facing businesses.

Dr Law's paper, which has been published in *Engineering Structures,* Volume 33, argues that the trend towards open-plan offices has changed the types of fire likely to occur in modern buildings and develops a new approach for designing large buildings to resist fire.

The paper aims to advance the understanding of how large fires can realistically be represented and how they can be applied to the design process. It also fuses the disciplines of structural engineering and fire engineering to give a unique insight into how real fires may affect real buildings.

Dr Sung-Han Koo, a BRE Global-funded PhD student and now a full-time employee of BRE Global, received a runner-up prize in the same category for his paper *Sensor-steered fire simulation* which was co-authored by Dr J Fraser-Mitchell (also a BRE Global employee) and Dr S Welch and was published in *Fire Safety Journal*.

Both winners graduated with doctorates in 2011 from the BRE Centre for Fire Safety Engineering at the University of Edinburgh (visit www.see.ed.ac.uk/fire/ for more information).

BRE PhD STUDENTS CONFERENCE 2011

BRE Trust contributed to the support of more than 30 PhD students during 2011

The PhD student convention hosted by the BRE University Centre of Excellence at Edinburgh commenced on Sunday 10 June with a team building exercise: following a nuclear disaster, the teams had to build structures of spaghetti, balsa wood or paper which were then subjected to a fire test. The exercise demonstrated that spaghetti performs well as an intumescent coating to protect a paper structure and the charring that is created acts as a barrier to further combustion.

The Chairs and PhD students gave presentations on their research to a small gathering of staff from BRE. The quality of presentations was excellent and the students managed in the short time allotted to introduce their projects, explain their findings so far and respond expertly to some difficult questions.

BRE PhD STUDENTSHIPS

In 2011 BRE Trust awarded funding to the following PhD studentships.

BRE Centre for Fire Safety Engineering – University of Edinburgh

- Fire performance of phase-change materials
- Smoke management for modern infrastructure

Six PhD students received financial support from BRE Trust in 2011.

BRE Centre for Sustainable Design of the Built Environment, Cardiff University

- Whole life-cycle costing in retrofit and refurbishment
- Delivering low-carbon buildings with Welsh timber as part of a Knowledge Economy Skills Scholarship (KESS)

Five PhD students received financial support from BRE Trust in 2011.

BRE Centre for Sustainable Engineering, Cardiff University

- Housing-led regeneration and energy practices of low-income households
- Intelligent cementitious composites

Five PhD students received financial support from BRE Trust in 2011.

BRE Centre for Energy Utilisation, University of Strathclyde

- Integrating envirodesign methodologies and information modelling tools to monitor, verify and measure design performance
- Demand-side design systems for geologic groundwater heat pump technology

Eight PhD students received financial support from BRE Trust in 2011.

BRE Centre for Innovative Construction Materials, University of Bath

- Value-added use for secondary aggregates in connection with the potential use of waste china clay in the St Austell eco-town development
- Fire and structural performance of non-metallic timber connections (awarded January 2012)

Six PhD students received financial support from BRE Trust in 2011.

Other universities

BRE Trust also provided funding support to a PhD student at Imperial College London.

PhDs completed in 2011

BRE Trust is delighted that the following BRE Trust PhD students were awarded Doctorates during 2011.

- Dr Yazan Abu Aisheh
  Identifying sustainable refurbishment options for listed post-war educational buildings
- Dr Adam Ervine
  Behaviour of damaged structures in fire
- Dr Thomas French
  Intelligent steering of emergency response by means of integrated fire models
- Dr Yousaf Khalid
  Intelligent controller and system design methodologies for systems in buildings with adaptive climate control
- Dr Angus Law
  Assessment of fire damaged concrete structures
- Dr Marek Prajer Novel
  Efficient production of high strength natural fibre composites for structural applications

RESPONSIVE MODE RESEARCH PROGRAMME

A broad spectrum of research projects has been approved for BRE Trust's Responsive Mode Research Programme for 2011/12

In June 2011, BRE Trust gave approval to a two-year £600 000 programme of research. To reflect BRE's broad spectrum of expertise the topics recommended for inclusion in the programme by the BRE Trust Research Committee chaired by Professor John Burland have a wide scope (Box 2). In compiling the programme, the committee has considered many issues such as:

- How best do we interact with and train professionals and pass on knowledge in the future world of e-books and smart phones?
- How do people interact with sophisticated technology in their homes?
- What are the implications of an ageing population and higher density living?
- How can more transient environments (from relief in disaster zones to shopfitting and exhibition spaces) be made more sustainable?
- How can we build a safer and more secure built environment?

Box 2: New research topics being funded by BRE Trust

Alternative approaches to realise the value and revenue from knowledge and information

Alternative materials and material security/resource availability in construction

BIM (Building information modelling)-based BREEAM

BREEAM: Is it delivering sustainable buildings?

BRE professional knowledge and free training portal

Building for the ageing population

Cornwall test case for Green Deal assessment methodology

Fires in combustible cavities

Fourth-generation district heating

Intruder resistance: new threats

Learning from European approaches to sustainability in the built environment

Mapping the sustainability impacts in fit-out and interiors for retail and commercial properties

People-friendly lighting controls

Site carbon manager

Sustainability assessment and enhancement of temporary built environments

The family in high-density developments: lessons from the past

Up-to-scratch and sustainable: guidance for school clients and planners

Working with professional institutions: professional development module on sustainable refurbishment

These questions and many others require rigorous science to confirm that we are dealing with these issues in a measured and considered way.

PUBLICATIONS PROGRAMME

The BRE Trust Publications Programme is now in its third year. The Trust's publications committee chaired by Hugh Ferguson met in March 2011 to select the publications that were to be funded in 2011. Forty-five BRE proposals were approved for inclusion in the publications programme with a budget of £500 000. Details of these proposals can be found in the final section of this *Review*.

All BRE Trust publications are produced by IHS BRE Press and sold through BRE Bookshop at www.brebookshop.com.

BUILDING4CHANGE UPDATE

BRE Trust's freely accessible online news and information resource, *Building4change.com*, has made significant progress over the past year. The website has now published more than 1000 articles featuring news, views, case studies and best practice guidance on the built environment in the UK and overseas. Its content is viewed by some 30 000 unique users per month.

At the end of 2011, BRE's quarterly magazine, *Constructing the future*, was incorporated into

Building4change.com. *Constructing the future's* in-depth content about BRE activities is now featured on the website, which was given a fresh new design in December 2011 to reflect the change.

The move builds on the success and reputation of both *Constructing the future* and *Building4change.com*, and allows information from BRE to be delivered rapidly and sustainably to an international audience.

BRE ARCHIVE

BRE Trust continues its support of the archive collection in 2011

In 2010 an extraordinary insight into almost a century of UK construction industry history was made available through a new online archive of research and guidance documents in a project set up by BRE Trust. Built environment experts at BRE have been at the forefront of UK construction developments since BRE was founded 90 years ago. The thousands of publications they have produced remain in the care of BRE Trust (owner of BRE).

During 2011 the collection was extended and now the archive includes nearly a thousand documents comprising:

- *Current Papers:* 720 research project summaries published from 1968 to 1983
- *Digests:* 130 reviews of contemporary building technologies published from 1948 to 1966
- *Overseas Building Notes:* 125 guidance notes on low-technology building methods suited to conditions in many developing countries, published from 1961 to 1994.

A further set of more than a thousand documents, including detailed research reports, will be added to the site in early 2012.

Much of the information in the documents has been superseded by more recent regulations and standards, but it often provides intriguing details about the research underpinning a number of current practices; the information on contemporary building standards and techniques can, for example, provide valuable insights for those now renovating older buildings.

The archive can be searched and documents downloaded for a small fee from www.brebookshop.com/archive.

LIMESNET

Launch of the new network, LimesNet, for developing and using low-impact materials

The LimesNet programme was launched in 2011 and now has 130 members. Fourteen overseas research missions have been approved, involving visits to 13 countries and over 50 universities or companies. Four workshops to review the findings of these missions are planned over the next 6 months, with a final conference planned for July 2012.

LimesNet is based in the BRE Centre for Innovative Construction Materials in the Department of Architecture and Civil Engineering at the University of Bath and is led by Professors Peter Walker and Tim Ibell. The network has been funded with a grant from EPSRC for its first 12 months.


Faculty of Engineering & Design

BRE Centre for Innovative Construction Materials

UNIVERSITY OF BATH

Home

LimesNet

This is the website for the **L**ow **I**mpact **M**aterials and innovative **E**ngineering **S**olutions research **Net**work - **LimesNet**

LimesNet is based in the BRE Centre for Innovative Construction Materials, in the Department of Architecture and Civil Engineering at the University of Bath. The network has been funded by the Engineering and Physical Sciences Research Council (EPSRC) for its first 12 months.

LimesNet is led by Professors Pete Walker and Tim Ibell at the University of Bath and has a high level of participation from a large number of academic and non-academic partners and members. Our Vision is to create a focused international multi-disciplinary community of leading academic researchers, industry members and other stakeholders, who share a common view for the development and adoption of innovative low impact materials and solutions to deliver a more sustainable built environment in the 21st Century.

The network provides a FORUM for developing and co-ordinating new research proposals and projects, international engagement, knowledge-sharing, dissemination of best practice and offering guidance to industry.

Join the network for FREE!

Professionals and Academics are welcome to join **LimesNet** free to enter an innovative and forward thinking dynamic community working towards the sustainable materials future of the construction industry. There is no better way to stay connected and updated on research thinking in the UK so join today.

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about this site

The vision for LimesNet is to create a focused international multidisciplinary community of leading academic researchers, industry members and other stakeholders, who share a common view for the development and adoption of innovative low-impact materials and solutions to deliver a more sustainable built environment in the 21st century. The network, which is free to join, provides a forum for:

- developing and coordinating new research proposals and projects
- facilitating international engagement
- sharing knowledge
- disseminating best practice
- offering guidance to industry.

To find out more, visit www.bath.ac.uk/ace/limesnet.

CORNWALL CHINA CLAY PROJECT

Cornwall Council, BRE Trust and BRE Wales partnership investigates new uses for china clay

This project will be undertaken in collaboration with BRE Wales and will support their role as primary consultants to the St Austell eco-town development. Outputs from BRE Trust-funded PhD students at the BRE University Centre of Excellence at Bath will feed into the design and decision-making process of the eco-town development. This provides a unique opportunity to test the practical application of prototype materials and conversely an opportunity for the research process to be informed by a practical design and construction project.

The project will investigate new uses for china clay waste. To date, applications for china clay waste have been in conventional, comparatively high embodied carbon materials such as concretes or in low-value bulk applications such as fill. This project seeks to develop innovative low-carbon materials based on natural binders, such as clay, and other low-impact materials for applications such as masonry blocks and materials for finishes (plasters, renders or mortars). The outcomes of the study will initially feed into the development of the St Austell eco-town in Cornwall.

For further information, please contact Andrew Sutton (email suttona@bre.co.uk).

WRAP

The partnership between BRE Trust and Waste Resources and Action Programme (WRAP) continued for a third consecutive year with a combined grant contribution from both organisations of £99 000 in 2011/12.

This funding enabled the continuation of work following on from the development and delivery of three Resource Efficiency Action Plans (REAPs) for three sectors:

- flooring
- joinery
- packaging.

The REAPs have been extremely effective in bringing the various sector supply chains together and have enabled industry to identify and deliver on the key actions needed to be more resource-efficient with their materials and products.

To ensure that the objectives published in the REAPs are achieved by delivering against the agreed actions, the work in 2011/12 has specifically focused on providing technical and research support to two core stakeholder groups established in 2010/11:

- Flooring Sustainability Partnership (FSP)
- Timber Resource Efficiency Partnership (TREP).

Each stakeholder group has met three times during the year. Two core outputs in 2011 have been the launch of online waste reporting and measurement tools for the flooring and timber sectors. These can be seen at:

- www.wastereporting.co.uk/flooring
- www.wastereporting.co.uk/timber.

One other significant output delivered in 2011/12 has been development of a fourth REAP for the rigid insulation sector. This follows on from the scoping study completed in 2010/11 to develop a cohesive plan of action for the sector to improve its resource efficiency across the supply chain.

The ultimate objective of delivering against the REAPs is to realise the significant potential for increasing resource efficiency within the industry as highlighted within the published REAPs. This will lead to:

- reduced materials usage
- reduced waste burden
- behavioural change within the sectors
- diversion of waste from landfill.

NHBC FOUNDATION

The NHBC Foundation works in partnership with BRE Trust to facilitate research and development, technology and knowledge-sharing, and the capture of industry best practice with a focus on housebuilding. Work is commissioned that is managed independently from BRE Trust's other programmes, and in 2011 this resulted in 14 new publications which are listed in Box 2. All are available in hard copy and pdf format from the NHBC Foundation website at www.nhbcfoundation.org.

During 2011, NHBC Foundation launched a blog and Twitter account to enable the Foundation to keep in touch and provide information on developments and emerging news across the housebuilding industry. The

***Box 2:* NHBC Foundation reports published in 2011**

Ref. no.	Title
NF23	Introduction to feed-in tariffs
NF25	Management of post-completion repairs
NF26	Home sale and handover
NF27	Milton Keynes: a sustainable future
NF28	Part L 2010 – where to start
NF29	Water consumption in sustainable new homes
NF30	Renewable energy systems of roofs on residential buildings
NF31	Zero carbon compendium 2011
NF32	Ground related requirements for new housing
NF33	Low carbon cooking appliances
NF34	Operational and embodied carbon in new build housing – a reappraisal
NF35	How occupants behave and interact with their homes
NF36	Fire performance of new residential buildings
NF37	Part F 2010: where to start

number of followers to these digital media has increased ten-fold over the course of the year.

SPONSORSHIPS

BRE Trust sponsors schools and conferences as part of its charitable objective to support education and communication of knowledge pertaining to the built environment. In 2011, BRE Trust provided sponsorship for:

- Pre-19 Schools Create Sport Challenge
- Parmiter's School in the Engineering Education Scheme
- RIBA Research Symposium, London, September 2011
- MicroGen 'II Conference, University of Strathclyde, April 2011
- A joint BRE Trust and British Photovoltaic Association (BPVA) conference, BRE Watford, July 2011, on photovoltaics and fire
- Conference on Training in Architectural Conservation (COTAC), Greenwich.

ICE President's Pre-19 Schools Create Sport Challenge

The Institution of Civil Engineers' (ICE) President's Pre-19 Initiative, Create Sport, gives 12–13-year-old school children in secondary education the opportunity to experience the disciplines and concerns of civil engineering and the built environment, at a time when they are about to choose subject options for public examinations. The project was sponsored by BRE Trust, the Ove Arup Foundation and the Kirby Laing Foundation.

The task involved designing a community sports venue and building a model of the team's design. the projects were judged in a national competition. Marks were awarded on structure, sustainability, aesthetics, community/society aspects, end users, legacy/flexibility and safety. In all, 798 students took part in 159 teams from 82 schools.

Parmiter's School

For the sixth consecutive year, BRE Trust provided Parmiter's School in Watford with support and financial assistance to enable a group of sixth-form pupils to participate in the Engineering Education Scheme (England), which is part of the Royal Academy of Engineering's 'Best' programme. This scheme gives pupils the opportunity to work on a project, guided by a mentor from a company, in this case BRE, so they can experience science, engineering and technology first-hand. The students' project on 'Assessing the performance of thermal mass of materials' gained them a gold CREST award in the British Association for the Advancement of Science CREST scheme.

RIBA Research Symposium

BRE Trust was delighted to sponsor the RIBA Research Symposium 2011 on 'The shrinking world' held at The RIBA in Portland Place, London, on 22 September 2011.

Globalisation and emerging markets present numerous opportunities for architects to export their skills all over the world. Given the difficulties faced by the UK economy, providing architectural services overseas has become increasingly vital to commercial survival.

The Symposium explored a range of issues concerned with providing professional services internationally: the technical difficulties of delivering projects in distant locations and to different cultures and the potential for information technology to be used as an aid to communication. It reviewed the ethics of exporting Eurocentric visions of the built environment to emerging economies. Leading speakers gave short presentations to a packed audience, and the symposium included opportunities for networking, including an after-lunch speed-dating session. The Keynote speaker was Jack Pringle PPRIBA of Pringle Brandon.

More information on the symposium can be found at www.architecture.com/TheRIBA/AboutUs/InfluencingPolicy/ResearchAndDevelopment/ResearchSymposium/ResearchSymposium2011.aspx.

MicroGen 'II Conference

BRE Trust and BRE Scotland were pleased to support the University of Strathclyde in hosting a successful 2nd International Conference on Microgeneration and Related Technologies: Microgen 'II, 4–6 April 2011. The conference attracted over 120 delegates from 16 countries. In all, 50 academic papers were presented and the conference's Industry Day featured 15 speakers from industry, government and end-user groups.

The conference focused on the future potential and role of thermal and electrical microgeneration technologies such as:

- photovoltaics (PV)
- solar thermal
- ground source heat pumps
- micro combined heat and power (CHP) (including fuel cells)
- biomass boilers
- micro-wind turbines.

The dedicated Industry Day provided an opportunity for those involved at the sharp end of microgeneration to relate their experiences, find out what other suppliers were doing and network with the worldwide microgeneration community.

Industry Day speakers included SSE, Scottish Power, UK Power Networks, Yanmar Energy Systems, The Energy Saving Trust, The Ground Source Heat Pump Association, A123, Community Energy Scotland and Senertec/Baxi.

Further details can be found at http://microgen11.supergen-hidef.org/microgenII/.

BRE Trust and British Photovoltaics Association Conference

Photovoltaics and fire: separating fact from fiction was held on 12 July 2011 at BRE's Watford site.

Photovoltaics (PV) are the most widely used renewable technology within the construction sector. However, following reports from outside the UK which question the fire safety of PV, the PV industry in some countries is being encouraged to join with the fire industry to develop guidance documents and checklists for operational fire fighters. These concerns have not yet arisen in the UK, so this seminar was a timely opportunity to pre-empt any such issues.

The conference brought together:

- over 100 UK fire service officers
- representatives from the PV industry
- representatives from the fire safety industry
- other interested professionals.

Delegates were able to exchange information, discuss the fire implications from the wider use of photovoltaics and consider potential solutions.

The feedback was positive and it was evident that specific guidance on the fire risks of PVs is needed by the UK fire and rescue service.

More information can be obtained by contacting Martin Shipp, Fire and Security Group, BRE; email shippm@bre.co.uk.

Conference on Training in Architectural Conservation (COTAC)

As part of a current project on the sustainability of large historic buildings and estates, BRE Trust provided sponsorship for a major conference on 'Improving thermal performance in traditional buildings' held in the King William Undercroft, Old Royal Naval College, Greenwich, London. The conference brought together some of the most knowledgeable researchers and practitioners in the field who presented the latest findings from recent research projects across the UK and some valuable case studies. The aim was to give building professionals practical guidance for their everyday roles in delivering improved thermal performance in traditionally constructed buildings.

SUNDAY TIMES BEST GREEN COMPANIES LIST

First Place for BRE in 2011 Sunday Times Best Green Companies List

The BRE Group achieved first place in the *Best Larger Firm with Low Environmental Impact* category in the Sunday Times Best Green Companies Awards.

BRE also achieved 11th place overall in the Top 60 Best Green Companies which acknowledges organisations with a pioneering and innovative approach to continually improving their environmental performance. Many of the innovations that have been implemented are direct outcomes of research funded by BRE Trust.

BRE is working towards its goal of being carbon-neutral by 2015, and is now diverting 99.8% of its waste away from landfill and fully expects this to be zero waste to landfill by the end of 2012 (ahead of target). An excellent community schools programme has been developed and a range of sustainable transport options have been introduced for staff, including a new staff bike pool.

The Sunday Times Best Green Companies combines both a robust methodology to measure actual corporate environmental performance, together with a survey of company employees at all levels of the company.

For more information, email Stuart Blofeld, Housing Group, BRE, at blofelds@bre.co.uk.

FOREWORD TO THE BRE TRUST RESEARCH PROGRAMME

The primary object of the BRE Trust is to support the research that is vital to preserving and enhancing the built environment and the health, safety and wellbeing of all who live, work and relax in it. The BRE Trust-funded research ensures that industry has access to the peer-reviewed evidence-based information, knowledge and tools that it needs to ensure a healthy, safe and sustainable built environment. It also ensures that there is up-to-date robust science behind current UK Government initiatives such as the reduction of carbon dioxide emissions through 'The Green Deal' and Feed-In Tariffs scheme.

The BRE Trust has access to unique resources: from the wide range of experts at BRE itself, from the five BRE University Centres of Excellence and from government, other academic institutions and industry.

The BRE University Centres of Excellence each has a specific area of the built environment to focus on. More detail on their specialties is given in Table 1 of the *Highlights* section but in summary: innovative sustainable materials at Bath, design and user behaviour and sustainable engineering in two centres at Cardiff, integrated energy modelling at Strathclyde and fire engineering at Edinburgh. These areas of focus have been chosen to complement the specialist areas that exist at BRE.

This *Review* brings together summaries from some of the BRE Trust-supported research completed in the past 12 months and includes contributions from BRE and from the BRE University Centres of Excellence and their PhD students. It includes research on materials and their disposal, renewable energy, sustainability, fire and security. As the following pages show, the BRE Trust is in a unique position to draw together a wealth of expertise and knowledge to carry out its research and maintain the status of BRE as an impartial and highly respected strategic research organisation in the UK and internationally.

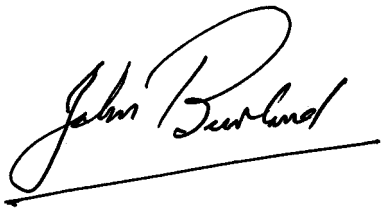
It is clear from the spread of topics covered that the 'built environment' is a large subject with many constituent parts and a wide range of expertise is needed to carry out meaningful research. BRE and its university partners are fortunate in that they can create powerful synergies by bringing their combined expertise to bear on the most important problems that are likely to face us in the built environment.

The statistics for existing buildings in the UK are startling and speak for themselves:

- 78% of existing domestic and 60% of non-domestic buildings will still be in use in 2050
- 18% of existing buildings have an Energy Performance Certificate rating of F or G
- 4 million households live in fuel poverty
- 5.2 million properties are at risk from flooding
- poor housing costs the NHS in excess of £600 million per year
- an extra 5.5 million people will be more than 80 years old in 20 years' time, which will further increase the burden on healthcare
- greenhouse gas emissions increased by 14% in the residential sector in 2009/10 (partly due to a cold winter but this still indicates that more action is needed).

With these statistics in mind, the BRE Trust is proud to support a new three-year thematic research programme on 'Future Cities' in collaboration with information technologists and energy providers to create the robust science-based information, knowledge and tools needed to address these really important issues.

I look forward to bringing you an update in the next *BRE Trust Review*.



Professor John Burland CBE, FREng, FRS
Chairman
BRE Trust Research Committee

PS If you would like to suggest ideas for research or would like to know more about the research programmes run by BRE Trust please look at the BRE Trust website at www.bretrust.org.uk

MATERIALS

INNOVATIVE LOW-CARBON CEMENTITIOUS BINDERS BASED ON AGRICULTURAL AND INDUSTRIAL WASTES FOR SUSTAINABLE CONSTRUCTION

Keith Quillin

Building Technology Group, BRE

SUMMARY

This project is one of a group of inter-related BRE projects assessing the potential for using alkali-activated materials as binders in the manufacture of concrete products.

BACKGROUND

Alkali-activated ash, clay and slag binders present significant opportunities for reducing CO_2 emissions associated with cement and concrete manufacture in the UK. Portland cement manufacture in an efficient plant emits about 0.83 tonnes of CO_2 per tonne of CO_2 produced. Consequently, a number of alternatives to Portland cement are being developed. The current project has focussed on one of these alternatives: alkali-activated binders in which materials such as clays, and industrial by-products such as slags and ashes, are mixed with a high pH chemical activator.

Alkali-activated binders gain strength through chemically induced polymerisation of silica components in the ashes and slags used. Significant CO_2 savings can be achieved.

BRE is currently working with precast manufacturers to establish that alkali-activated systems can, in principle, be used in commercial precast concrete manufacture. BRE's work has involved a number of projects funded by the Carbon Trust, the TSB and the BRE Trust. The current project falls within this wider programme and has been carried out in parallel with a Trust-funded PhD as outlined below.

RESEARCH PROGRAMME

The project has been carried out as part of a suite of BRE projects that have assessed the use of alkali-activated ashes, slags and clays as binders in concrete products. These projects have built on work carried out at BRE and elsewhere to assess a wide range of ashes, slags and clays in the context of their use in formulating binders for concrete that are suitable for commercial use as an alternative to Portland cement (Figure 1). These materials were investigated:

- industrial ashes and slags
- agricultural ashes (including those arising from biofuels)
- clays and clay wastes

The work has assessed and identified formulations that have the potential for use in commercial concrete manufacture in the UK.

The current project was set up to enable collaboration with a BRE Trust funded PhD studentship being conducted by Kofi Abora at Bath University. It has involved a study to assess the susceptibility of concretes made using alkali-activated binders to potentially damaging alkali aggregate reactions (AAR) in which reactions between aggregate and high pH cementitious components led to expansive products. The work has used procedures developed at BRE for use with Portland cement concretes to assess the performance of concretes made using alkali-activated binders. These procedures use a range of aggregate types (including those known to be susceptible to AAR) and storage conditions with concrete specimens being stored for long periods in warm, moist conditions in order to induce deterioration.

Kofi's PhD has also reviewed the environmental impact of alkali-activated concretes used in the AAR study.

The work has been written up in a number of papers (see section on *Research output*). These complement publications prepared by BRE under other programmes.

PROJECT OUTCOMES/CONCLUSIONS

The project has demonstrated that concretes made using alkali-activated binders have good performance relative to that of PC concrete. Other work has shown that these concretes have good durability performance in the context of a wider range of common deterioration mechanisms. The results of the work are being included

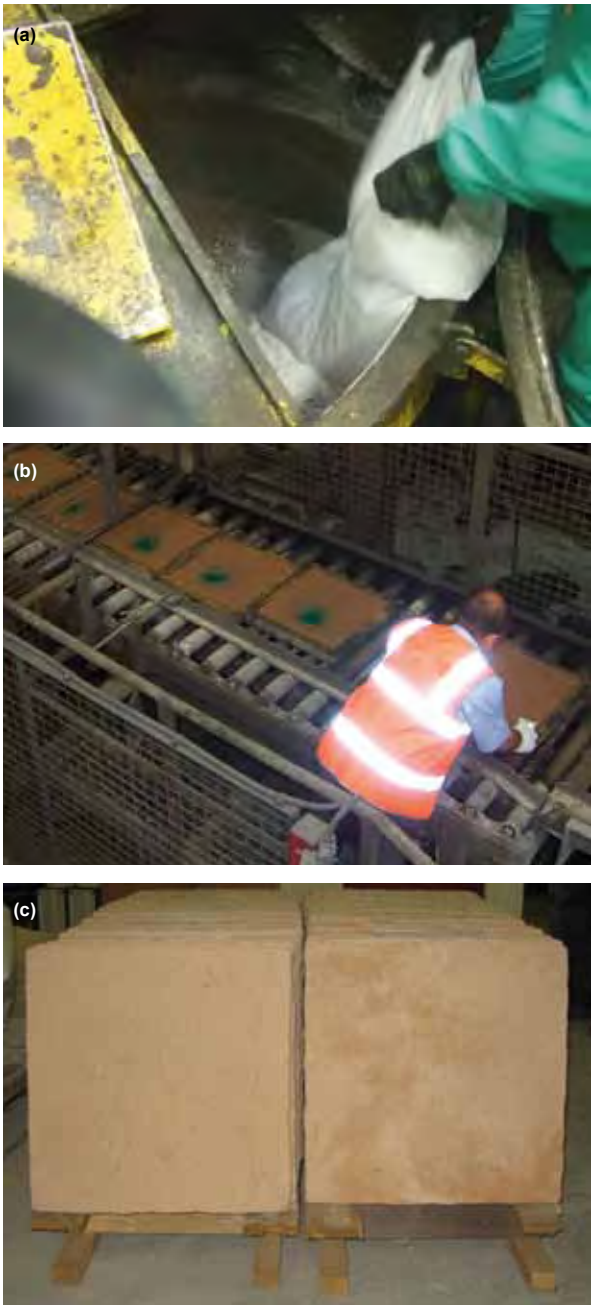


Figure 1: Precast concrete manufacture: (a) solid binder being added to concrete plant mixer, (b) concrete products compacted in mould on production line, (c) finished concrete paving slabs after demoulding

in the PhD Thesis and have been published in conference proceedings and in the *BRE Trust Review 2010*.

Work on the environmental impact of alkali-activated concretes used in the AAR study has shown that alkali-activated binder concretes can reduce embodied CO_2 by over 50% relative to conventional PC concrete. The results have been included in papers for relevant scientific conferences and will be published in a BRE *Information Paper* that is currently being prepared for publication.

RESEARCH OUTPUT

The project has produced a number of outputs. These complement other publications prepared under other BRE projects in this field.

Abora K, Dunster A and Quillin K. Alkali-activated binder concrete in construction: assessing the environmental impact. BRE Information Paper (in preparation).

Abora K, Paine K, Quillin K and Dunster A. Properties and performance of alkali-activated fly ash/hydrated lime concrete. Paper to be presented at 8th International Conference on Concrete in the Low Carbon Era, Dundee, 9–11 July 2012.

For further information, contact Keith Quillin,
Tel: 01923 664893, Email: quillink@bre.co.uk

DEALING WITH DIFFICULT DEMOLITION WASTES

Katherine Adams and Gilli Hobbs

Building Futures Group, BRE

SUMMARY

The overall aim of this project was to provide practical recovery guidance for 'difficult' demolition wastes. First, it was necessary to identify product and waste types that are difficult to recover or recycle. The priority group, including carpet underlay, insulated concrete formwork, industrial batteries, structural insulated panels (SIPs) and smoke alarms, was examined in more detail to consider the potential for improving levels of reuse, recycling and recovery. A wider directory of potentially difficult waste types was produced, together with a short summary of recycling and recovery issues that may need to be considered.

BACKGROUND

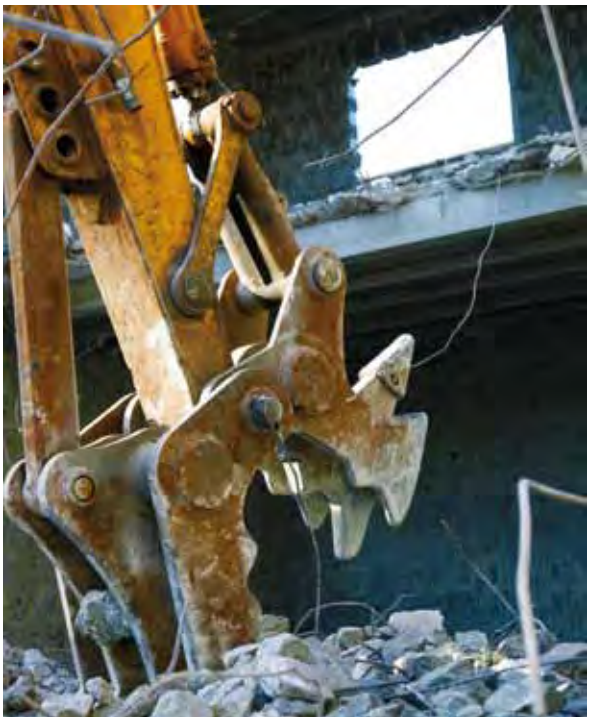
Difficult wastes (ie wastes that are difficult to recover) are becoming more noticeable from the major refurbishment and demolition of buildings in the UK. This is largely because the lifetime of some buildings can be as little as 30 years so products that have been used within these buildings are now entering the waste stream. Data from the National Federation of Demolition Contractors (NFDC) show that the amount of waste going to landfill has increased substantially in recent years[1].

Current products that have reached the end of their life and may be classed as 'difficult' wastes can include:

- batteries
- solvents
- insulation products containing ozone-depleting substances
- waste electrical and electronic equipment (WEEE)
- smoke alarms
- some flooring products
- asphalt-based roofing products.

They are termed 'difficult' as they may be problematic to recover, which could be due to their material composition, techniques of demolition/strip out, contamination, value, etc. and as a result they are likely to end up in landfill. They may also be products with a relatively high environmental impact because of their hazardous nature, embodied energy or global warming potential; obviously, not recovering these products at the end of their life adds to their overall environmental impact.

Products that may be considered difficult wastes in the future may arise from modern methods of construction (MMC). The use of traditional brick and block construction is still predominant in the UK; however, the requirement to achieve zero-carbon homes by 2016 will



act as a driver to an increase in the number of homes being built using MMC. There is little knowledge in the house building sector regarding the future recyclability of the materials incorporated into buildings using MMC. It is predicted that when these houses reach the end of their life (defined as 60 years using the whole life costing accounting methodology), it is likely that some of these materials will not be easy to recycle.

RESEARCH PROGRAMME

The overall aim of this project was to provide cost-effective and practical recovery guidance for 'difficult' demolition wastes. This included:

- provide an understanding of difficult wastes entering the demolition and refurbishment waste stream, both now and potentially in the future, in terms of type, amount, issues and current recovery routes
- prioritise difficult wastes for further action by using agreed criteria considering the following:
  - environmental impact
  - amount being landfilled
  - cost
  - usage
  - recovery routes
- trial improved reuse, recycling or recovery of the prioritised difficult waste. This was through practical trials and also through interviews with demolition contractors to determine what could be technically and economically feasible
- develop recommendations for the practical and cost-effective recovery of defined difficult wastes.

PROJECT OUTCOMES/CONCLUSIONS

Certain demolition waste types are 'difficult' for a number of reasons. Often, the main issue relates to the cost of removing the product or material in such a way as to facilitate reuse or recycling. However, for many of these product types, there are limited routes for recovery. This in itself creates instant barriers in that the demolition contractors are not aware of these options and the cost of transportation to a facility, that could be hundreds of miles away, is potentially high. Ultimately, the waste will be transferred to the lowest cost disposal or recovery option, unless the client has specifically required certain levels of recycling and recovery.

There are several approaches to improving the recovery of difficult demolition, depending on whether it is an existing development or a planned development.

Existing developments

The demolition contractors' knowledge, experience and commitment to maximising reuse, recycling and recovery of wastes arising from a particular type of construction will be the main influence on levels of recovery in an existing development. BRE is therefore working with NFDC to raise awareness of recovery opportunities, especially for building types for which they have little experience, such as innovative building systems.

There is also a continuing need to develop new recovery routes for those products and materials that are already embedded into our buildings and that we know have a limited capacity to be recovered, whether due to technical, economic or legislative barriers. This is where specific construction product activities, in the form of Resource Efficiency Action Plans (some of which are part-funded by BRE Trust), can make an impact by working across the supply chain of these products to identify gaps in end-of-life recovery opportunities and subsequent actions to explore these opportunities in more detail.

Planned developments

The designer and main contractor will have the greatest influence over the future recyclability of the buildings in a planned development. The principles of 'designing for deconstruction' need to be factored into the design, and then transferred through to the construction of the buildings. For example, having designed a building to have fixings which facilitate dismantling for reuse of components, it is important that these fixings are actually used to construct the building. In addition, when a building is designed to be deconstructed, there must be a process for passing information on the recommended method for taking the building apart to the building owners, and eventually to the demolition contractors.

This latter area is where the greatest need for future research lies.

- Developers of new building systems should have a producer responsibility (if not legally, then ethically) to consider the end-of-life implications of their products. Their recommended approach to deconstruction of their products should be advertised and any materials/fixing techniques that will cause problems in the future should be phased out.
- There is no recognised way of rating a building on its design elements to promote future reuse and recycling. If a rating system was devised, it would be possible to provide credits or ratings for achieving better practice.
- There is also a fundamental knowledge transfer gap through the building life cycle to ensure the planning to improve future recyclability is followed through and eventually recognised at end-of-life.

Finally, the market for reuse is unclear for many products, being fraught with concerns over continuing 'fitness for purpose' and the mismatch between products coming onto the market and an appropriate reuse application becoming available. Traditionally, this has been enabled through a widespread network of reclamation companies, typically dealing in higher value architectural items and materials. At this point in time, the value of modern construction products in a reuse application is often too low to make it economically feasible to involve a third party in collection and storage until a suitable reuse application becomes available. This suggests that there will need to be more support from the manufacturers and distributors of lower value, potentially reusable construction products and materials to enable their products to be reused.

RESEARCH OUTPUT

More information about the findings of this research project will be given in a BRE Trust Report which is being drafted for publication in 2012:

Adams K, Hobbs G & Yapp C. Dealing with difficult demolition wastes: a guide.

REFERENCE

1 National Federation of Demolition Contractors (NFDC). Verbal communication, 2010.

For further information, contact Gilli Hobbs,
Tel: 01923 664856, Email: hobbsg@bre.co.uk

BRE CENTRE OF EXCELLENCE FOR INNOVATIVE CONSTRUCTION MATERIALS, UNIVERSITY OF BATH

Peter Walker

BRE Trust Professor of Innovative Construction Materials

It has been a busy and exciting year for the BRE Centre for Innovative Construction Materials (BRE CICM) at the University of Bath. New research income, from a variety of sources including EPSRC, FP7 and EACI, has exceeded £2 million in 2011. BRE CICM has now grown into a multi-disciplinary team of over 60 researchers (full-time academics, contract research staff, and post-graduate students) drawn from across the Faculty of Engineering & Design at the University of Bath. The main research activities of BRE CICM continue to include work in the fields of:

- advanced composites in construction
- concrete structures
- low-carbon building materials
- timber engineering and materials
- structural masonry
- seismic engineering
- structural conservation and vulnerability assessment.

In March 2011, Dr Shane Donohue joined the university as a lecturer in geotechnical engineering. Shane's research is primarily focused on the fields of geotechnical and geo-environmental engineering. Specifically, his current research is concerned with environmental and engineering applications of geotechnical and geophysical site investigation techniques, including engineering characterisation of materials, slope stability (peat slopes, quick clay, embankments) and wastewater and landfill contamination. In addition, he is also interested in the application of these methods to other civil engineering sub-disciplines, such as transportation and structural engineering.

BRE CICM is lead partner for the Engineering and Physical Sciences Research Council (EPSRC)-funded network on low impact materials and engineering solutions (LimesNet). In September 2011, the Centre hosted the launch event for the network attended by over 70 delegates from academia and industry (Figure 1). The network provides a forum for:

- developing and coordinating new research proposals and projects
- international engagement
- knowledge-sharing
- dissemination of best practice and offering guidance to industry.

Figure 1: LimesNet network event

LimesNet has funded 14 international missions to support collaborative engagement with leading research groups and centres from around the world. Four themed workshops and a conference will be organised by LimesNet in 2012.

Eight new PhD research projects have commenced over the past 12 months. Project currently in progress include:

- *Jonathan Skinner* is undertaking a project on thin structural toppings for timber floors. The most likely form of failure for a timber floor is excessive vibration, that is an unsatisfactory dynamic response. This study is looking at toppings of 15–20 mm thickness (Figure 2). The PhD is investigating the improved dynamic response possible with the addition of a thin topping. The performance and optimisation of shear connectors will be studied and, through analytical and experimental studies, the work will enable the dynamic response of thin-topping composite floors to be predicted. Jonathan's project is supported by BRE Trust.
- *Adamantia Zografou* has joined BRE CICM to undertake a PhD supported by BRE Trust to develop novel applications for china clay waste materials. Working with Dr Andrew Heath of BRE South West, and stakeholders in Cornwall, the PhD project is evaluating current waste streams and secondary aggregates for higher-value construction products.

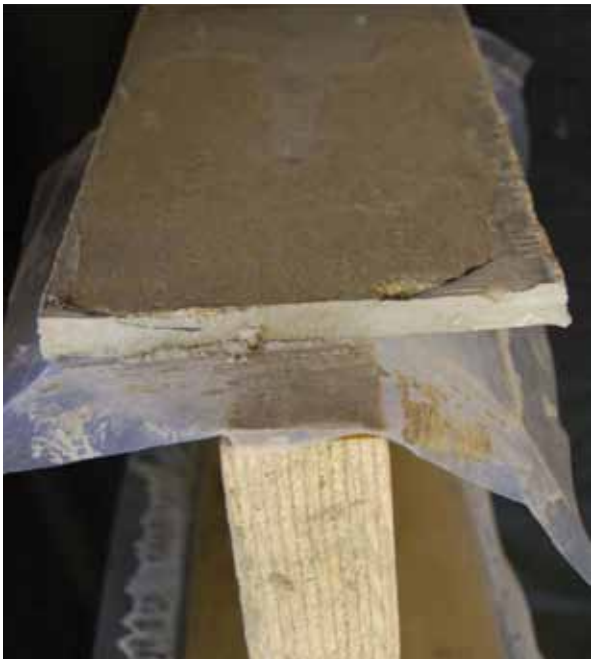


Figure 2: Thin structural concrete topping on a timber beam

- *Hector Archila-Santos* is now in the second year of a PhD study investigating and developing riven bamboo composite panels for housing construction. An architect, Hector is characterising materials, developing panel design and conducting structural testing. In December 2011 the Centre hosted a party of visiting researchers from the Chinese Academy of Forestry (Figure 3) to discuss collaborative work on bamboo materials in construction. Hector's work is supervised by Dr Martin Ansell and is supported by the Colombian Government.

Figure 3: Delegation from the Chinese Academy of Forestry visiting the Centre in December 2011

- *Monika Grusova* joined the Centre in October 2011, having completed her Masters at the University of Edinburgh, to undertake research on FRP strengthening of reinforced concrete T-beams under the supervision of Professor Tim Ibell. Monika's work is supported by EPSRC.
- *Daniel Maskell*, supported by a University of Bath research studentship, is carrying out PhD study to explore and develop low-carbon forms of improving water resilience of unfired clay (earth) masonry. He is supervised by Professor Peter Walker.
- *Manuel Nuño* began his PhD work in October 2011. Sponsored by a University of Bath research studentship he is working with Dr Richard Ball on the development of photo-catalytic coatings for building materials.

In further recognition of the high quality research in the Centre, staff received a best paper award from the Institution of Structural Engineers. The paper 'Shear design of circular concrete sections using the Eurocode 2 truss model' published in *The Structural Engineer* and authored by John Orr, Dr Antony Darby, Professor Tim Ibell, Dr Steve Denton and Dr John Shave received the Henry Adams Diploma for 2011.

For further information on these projects or those that follow, contact Professor Peter Walker,
Tel: 01225 386646, Email: p.walker@bath.ac.uk

FIBRE-REINFORCED POLYMER STAY-IN-PLACE PARTICIPATING FORMWORK FOR FLOOR SLAB CONSTRUCTION

Antony Darby, Xian Gai, Tim Ibell and Mark Evernden

BRE Centre of Excellence for Innovative Construction Materials
University of Bath

SUMMARY

This project involves the development of a new concept for a fibre-reinforced polymer concrete composite floor system. The system consists of a moulded glass-fibre-reinforced polymer (GFRP) grating bonded to rectangular pultruded GFRP box sections as structural formwork for a concrete slab. Holes cut into the top flange of the box sections at a variable spacing allow concrete GFRP dowels to be inserted to act as shear studs. Experimental results indicate that this type of shear connection provides robustness and ductility to the system, thus solving one of the major problems associated with construction using FRPs.

BACKGROUND

Conventional reinforced concrete structures are fabricated by casting concrete in temporary formwork which is usually made from wood or steel. The formwork is often held in place by temporary scaffolding. On hardening of the concrete, the formwork and temporary supports are removed, revealing the concrete structure within. Permanent participating formwork, also referred to as a stay-in-place (SIP) system, remains structurally integrated with the concrete. It not only acts as a self-supporting formwork during the construction phase, but also acts as permanent external, structural reinforcement.

The elimination of the need for conventional steel reinforcing bars can significantly simplify the engineering and detailing process, as well as save time during construction. In the past few decades, fibre-reinforced polymer (FRP) composite materials have been investigated as an alternative solution to the use of conventional steel reinforcement in new-build structures and as external reinforcement for the retrofitting and strengthening of existing structures[1–4]. These materials have numerous potential advantages over traditional materials, particularly in terms of weight-to-strength ratio and durability. However, there is a significant drawback with FRP materials. Unlike steel, which yields plastically, FRP remains linear elastic to failure. When FRP is used as reinforcement for a concrete structure, a lack of overall ductility results and, hence, there is the possibility of sudden and unexpected brittle failure. It is therefore necessary to introduce ductility by means other than tensile reinforcement.

RESEARCH PROGRAMME

The objective was to develop a prototype of a structurally integrated stay-in-place FRP formwork system which would behave in a ductile manner when overloaded. The concept developed (Figure 1) was to provide:

- a thin concrete topping within the compression zone of the floor
- FRP box sections in the tension zone.

The rationale for this is that concrete is good in compression but is not useful in the tension zone where it only adds to dead weight. Conversely, FRP is poor in compression but good in tension and does not require concrete cover to provide corrosion resistance. Therefore, the described arrangement makes best use of the two materials. The two elements are connected longitudinally by the use of transverse FRP rods which act as shear connectors. These aim to provide a robust bond between the two components.

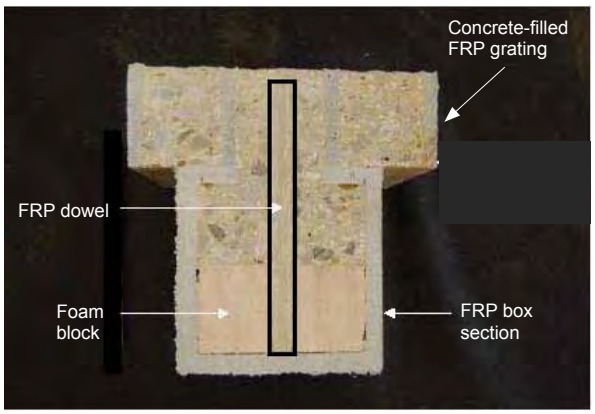


Figure 1: Proposed concrete/FRP composite slab cross section

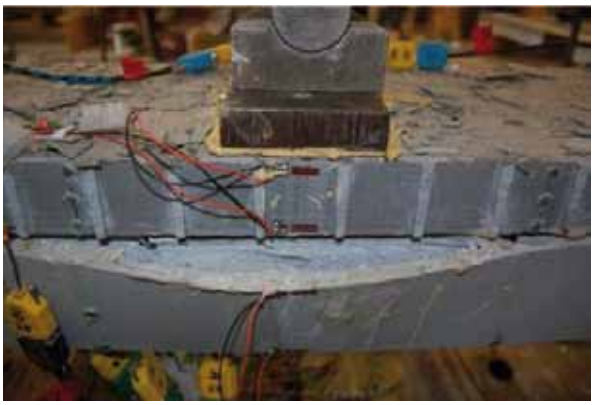


Figure 2: Buckling failure of box sections within the composite system

To provide ductility to this combined concrete/FRP system, two approaches were investigated.

- First, if the FRP cannot behave in a ductile manner, then can ductility be extracted from the concrete? Concrete usually has little ductility, but by confining the concrete, its ductility (and strength) can be increased. An FRP grating was therefore used in the compression zone to confine the concrete in this zone.
- The second way of achieving ductility was to allow a gradual failure at the interface between the concrete-filled grating and the FRP box section. A simple adhesively bonded connection would fail suddenly in a brittle manner, but by embedding FRP rods in the concrete-filled cells of the grating and within partially filled holes within the FRP box section below, a robust bond could be formed with the potential for a gradual debonding to occur.

A series of tests was performed on:

- the individual components (box section, concrete-filled grating and bond interface), which provided an understanding of the fundamental behaviour
- the complete system in the form of 500 mm wide, 3 m span floor sections. Ultimate failure of the floor was found to be by gradual debonding along the concrete/FRP interface followed by buckling of the FRP box sections (Figure 2).

A theoretical model was developed to represent behaviour. The model allowed prediction of the end of the fully composite elastic phase, the partial interaction behaviour during debonding, and the final buckling failure condition, based on constituent models from the component tests. The model provided excellent predictions of results (Figure 3).

PROJECT CONCLUSIONS

The project demonstrated the following:

- A robust connection between tension and compression elements within the floor system is essential to prevent brittle failure and introduce ductile behaviour. The use of transverse FRP rods between the concrete and FRP box sections provided this robustness in a similar way to conventional shear connectors.
- Increasing the ductility of the concrete in compression could be achieved by confining the concrete with an FRP grating. This allowed much greater strain capacity (100% higher than normal) to be achieved which in turn allowed more efficient use of the FRP in tension, although this resulted in large deflections.
- Ductility of the overall section could be provided by a combination of gradual de-bonding and crushing of the concrete in compression.
- Serviceability criteria governed behaviour due to the relatively low stiffness of the floor system.

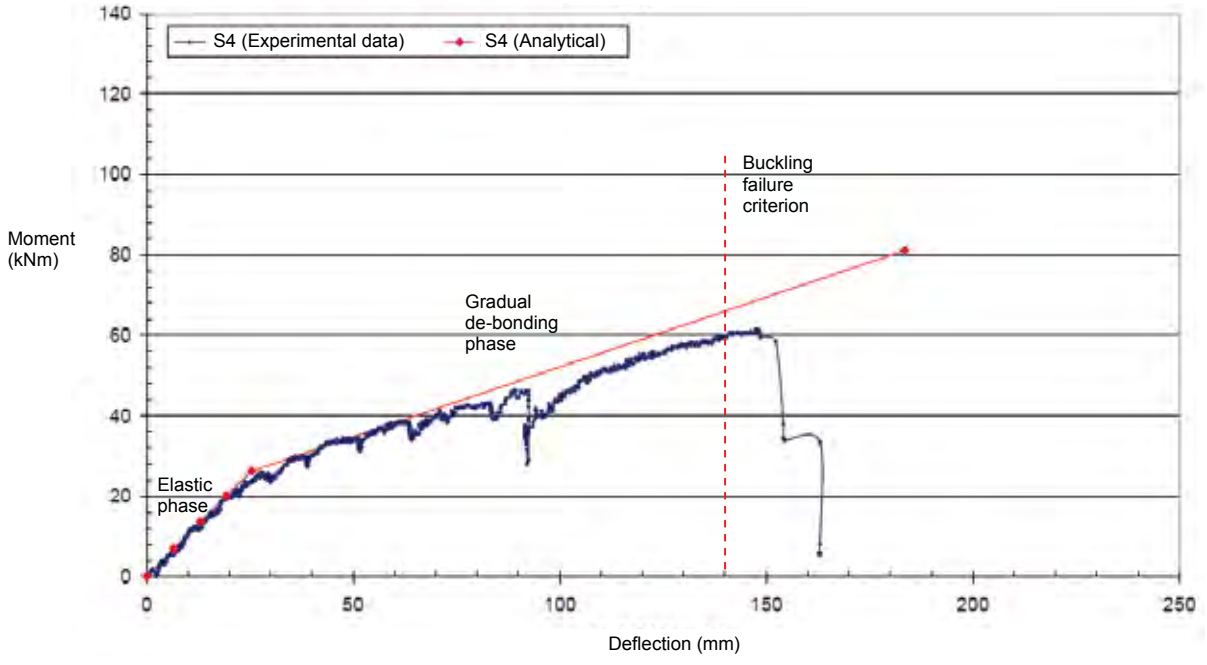


Figure 3: Typical moment deflection behaviour of slab and analytical prediction

- Simple analytical procedures allow the behaviour to be predicted.

While the project has demonstrated that the concept of a ductile fully polymeric permanent participating formwork can be achieved, further work is required to ensure sufficient stiffness of the system. Other issues such as fire resistance, continuity and the possibility of a two-way spanning floor also require investigation.

PUBLICATIONS/RESEARCH OUTPUT

Gai X, Darby AP, Ibell TJ and Evernden MC. Innovative reinforcement for fabric formed concrete structures, Proceedings of 10th International Symposium on Fiber Reinforced Polymers Reinforcement for Concrete Structures (FRPRCS 10), Tampa, FA, 2–4 April 2011.

Gai X, Darby AP, Ibell TJ and Evernden MC. FRP concrete composite floor slabs. Proceedings of 5th International Conference on Advanced Composites in Construction (ACIC 2011), Warwick University, Coventry, 6–8 September 2011.

Gai X, Darby A, Ibell T, Evernden M and Matthews S. FRP stay-in-place participating formwork: design considerations and preliminary testing. Proceedings of 4th International Conference on Advanced Composites in Construction (ACIC 2009), University of Edinburgh,1–3 September 2009, pp 376–387.

Gai X, Darby A, Ibell T and Evernden M. Development of a robust mechanical shear connector between FRP and concrete for FRP stay-in-place participating formwork. Proceedings of 9th International Symposium on Fiber Reinforced Polymers Reinforcement for Concrete Structures (FRPRCS-9), Sydney, 13–15 July 2009.

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1 Larralda J. Feasibility of FRP molded grating-concrete composite for one-way slab system. Proceedings of the Materials Engineering Congress, ASCE, Atlanta, GA, 10–12 August 1992. pp 645–654.

2 Dieter DA, Dietsche JS, Bank LC et al. Concrete bridge decks constructed with fiber-reinforced polymer stay-in-place forms and grid reinforcing. Transportation Research Record, 2002, 1814, 219–226.

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DEVELOPMENT OF HEMP-BASED COMPOSITE MATERIALS FOR CONSTRUCTION

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SUMMARY

Hemp-lime is a low-impact renewable composite material currently used mainly for solid wall insulation in combination with a structural timber frame. It has gained some popularity in recent years but there is still comparatively little scientific understanding or data on the performance of the material. This PhD project aimed to characterise hemp-lime constituent materials (hemp shiv and lime binder) and composite material properties, and to relate development of physical performance to chemical changes (hydration and carbonation) of the lime binder with time.

Hemp-lime is made from hemp-shiv and a formulated lime-based binder, mixed together with water to produce a composite building material. Hemp-shiv is the woody inner section of the plant stem, making up 40–60% (by mass) of the *Cannabis sativa L.* plant[1]. Hemp-lime uses the shiv as a bio-aggregate. In the UK, hemp is grown as a break crop and harvested after around 4 months. Once harvested, the hemp is processed, separating the shiv from the fibre and removing any dust, dirt and particulates. Other uses of shiv include animal bedding.

Formulated limes are blended binders based on air-lime (calcium hydroxide) or natural hydraulic lime, mixed together with a hydraulic component, typically Portland cement and/or pozzolanic material such as ggbs or fly ash[2]. Further ingredients to improve the consistence, reduce setting time, improve permeability or enhance durability may also be added. Formulated limes are preferred to Portland cement-based binders for hemp-lime as they provide better vapour permeability. Other uses include renders, plasters and mortars. In hemp-lime, the hardened binder creates a matrix connecting the shiv particles together. Formulated lime binders have been developed specifically for hemp-lime and are marketed in the UK under trade names such as Tradical™ HB and Batichanvre™. Following their initial hydraulic set, formulated lime binders gain strength through the slower process of carbonation.

The main use of hemp-lime is for non-structural building applications, where the material is cast or sprayed around a primary structural frame (Figure 1) and finished with a lime rendering. The primary function of hemp-lime is therefore to create a durable, weathertight external non-structural external fabric. Hemp-lime offers good thermal and acoustic insulation, enabling it to be used in solid walls without the need for additional insulation materials.

Figure 1: Casting a hemp-lime wall

By reducing the formulated lime binder content within hemp-lime composite mixes, it is possible to reduce material costs, embodied carbon and density (so improving thermal insulation). There is little published data on the mechanical performance of hemp-lime for these lower density mixes. The study therefore reports on the mechanical characteristics of low-density hemp-lime. Concurrent with mechanical property tests, chemical testing was used to map the progression of carbonation across the cross-section of the specimens.

RESEARCH PROGRAMME

Constituent material properties

The hemp used within this study is distributed under the trade name Tradical™ HF and was grown and processed by Hemp Technology Ltd (formerly Hemcore Ltd) in the UK. Hemp-shiv is delivered to site in pre-packaged bales

and has not been chemically treated. Three commonly used hemp-lime proprietary binders were compared. The first and second were two different formulations of UK-produced Tradical™ Hemp Binder (THB). Tradical™ binders are based on CL90 air lime with the addition of hydraulic components and other additives to improve porosity and consistence. The third was a natural hydraulic lime-based binder produced by French lime producers St Astier called Batichanvre™ (BC).

The strength of all three binders was measured in accordance with BS EN 196-1:2005[3]. The binders were mixed together in proportions of 2 parts binder to 1 part standard graded sand. BC gave the highest strength of all binders with a mean 28-day compressive resistance of 30.1 N/mm^2, which was up to three times greater than that of the THB binders. This higher strength is most likely to be an indication of a higher proportion of hydraulic binder within the BC material. For the purpose of this study, THB was used as the control binder since it is the most widely used hemp binder in the UK; it was the only binder used to compare mechanical differences due to changes in density.

Composite specimen preparation

Current practice specifies 1.5 or two parts binder to 1 part hemp, combined with around 2 parts water, producing a final density of 275 or 330 kg/m^3. This study compares the performance of 330 and 275 kg/m^3 mixes. In addition, the study also reports on tests carried out on mixes of 1 part binder to 1 part hemp, producing a final material with a density of approximately 220 kg/m^3.

A total of 54 (150 mm diameter × 300 mm high) cylindrical specimens of hemp-lime were fabricated in order to compare the strength and stiffness properties at three different air-dry densities (220, 275 and 330 kg/m^3). A 2:1 height:diameter ratio was adopted as used in previous research. Specimens were tested at ages of 14, 28, 91 and 180 days. The materials were prepared using a pan concrete mixer. Specimens were cast in wax-dipped cylindrical cardboard moulds and initially sealed with plastic caps. At these low densities, no compaction was required to obtain the specified density. All specimens were cured at a temperature of 20°C ±1°C and relative humidity of 60% ± 5%. The cardboard moulds were removed after 1 week allowing uniform drying and carbonation.

Specimen testing regime

The hemp-lime cylinder specimens were subject to compression testing at different ages up to 180 days (Figure 2). In addition, rates of drying and dry densities were monitored. In combination, chemical development of the lime binders (hydration and carbonation) was analysed using x-ray diffraction and thermogravimetric analysis. Carbonation was also measured on specimens using phenolphthalein indicator testing.

PROJECT OUTCOMES/CONCLUSIONS

The aim of this study has been to characterise the mechanical properties of low-density hemp-lime materials and investigate their drying and carbonation behaviour. In fulfilling this aim, novel test procedures have been successfully developed which have contributed to development of standard specifications.

Figure 2: Compression testing of hemp-lime specimen

Conclusions from the project include:

- the ultimate strength of hemp-lime is a function of the percentage of wet binder used during mixing, although it is not directly related to the strength of the binder.
- the ultimate compressive strain at failure decreases with time following carbonation of the binder.
- the initial tangent modulus is increased with the percentage of wet binder used and with material density.
- carbonation of hemp-lime commences at an early age and carbonation rates decrease with density.

PUBLICATIONS/RESEARCH OUTPUT

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LOW-CARBON CONCRETE Research on non-Portland cements

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SUMMARY

In recognition of the contribution of cement to carbon emissions worldwide, research has been investigating the use of cementitious systems that are inherently less CO_2-intensive than Portland cement, including calcium sulfoaluminate cements, supersulfated cements, and alkali-activated cements. The research has developed further fundamental understanding of the mechanisms by which these cements work and has provided data relating to the performance of concrete made with these cements, particularly when subject to environmental conditions typical of those in the UK.

BACKGROUND

The UK Government and construction industry have committed themselves to a strategy for sustainable construction based on reductions in carbon footprint and a reduction in consumption of natural resources. Within this strategy is a target to use more materials with lower environmental impact and encourage the use of responsibly sourced construction materials. Because concrete is the most widely used construction material, and because there is no practical alternative to its use for most modern construction projects, the provision of sustainable use of concrete is imperative for the achievement of these targets.

Because cement accounts for up to 98% of the embodied CO_2 (eCO_2) of concrete, it is through this aspect that the most significant reductions in eCO_2 can be achieved. In the short term, this can be achieved by blending Portland cement with other constituents and by reducing cement contents. However, in the longer term there is considerable interest in the use of alternative cementitious systems that are inherently less CO_2-intensive than those we currently use. These lower carbon cements may be based around a number of technologies, some of the most promising of which include:

- calcium sulfoaluminate cements (CSAC)
- supersulfated cements (SSC)
- alkaline ash binders.

These three technologies have been the subject of recent research funded by BRE Trust within this BRE Centre of Excellence.

RESEARCH PROGRAMME

Calcium sulfoaluminate cements

Calcium sulfoaluminate cements (CSAC) consist of:

- ye'elimite (naturally occurring form of calcium sulfoaluminate)
- belite
- aluminoferrite.

They have an eCO_2 which is approximately 35% lower than Portland cement. The primary hydration product is ettringite which forms at early ages (0–48 hours). To ensure that sufficient ettringite is formed, calcium sulfate (gypsum or anhydrite) is added either in the raw meal intergrinding process or as an addition at the mixer.

Currently, there is a scarcity of data on the durability of blended CSAC concretes. Therefore, research within the BRE Centre has investigated the effect of calcium sulfate content, source and chemistry on the properties of CSAC-based concrete[1]. Furthermore, although the addition of calcium sulfate is an important constituent in terms of ensuring the formation of an optimum quantity of ettringite, the research has been investigating whether it may be possible to form alternative stable hydration compounds by use of pozzolans and/or other fine materials and further reduce the eCO_2 of the concrete.

Research on combinations of CSAC and limestone has been of particular interest within this study and it has been observed that the limestone is both a chemically and mechanically active component of the combination[2]. The chemical contribution is due to partial restriction of the formation of monosulfate, with carboaluminate phases in minor amounts observed by thermogravimetric and x-ray diffraction analyses. However, an amorphous structure accommodating ettringite is maintained (Figure 1). The

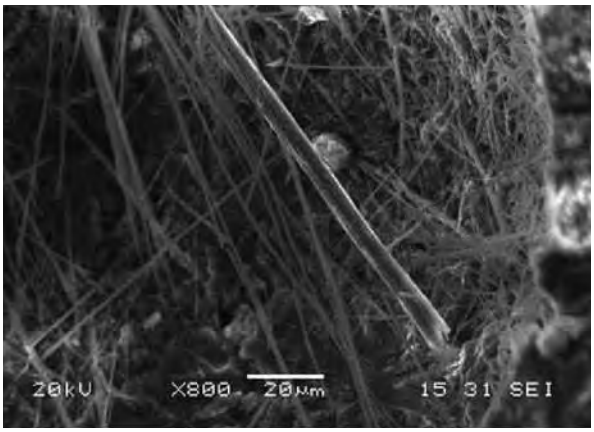

Figure 1: Scanning electron image of a CSAC/limestone combination at 28 days

mechanical contribution reflects on the high concrete strengths and low chloride diffusion coefficients, but this occurs at low water–cement (w/c) ratios; hydrates were found to interlock with the excess carbonate particles more effectively at a w/c ratio of 0.35.

Furthermore, there has been evidence that CSAC/limestone concretes exhibit better resistance to sulfates and chloride ingress than Portland cement concretes, although the addition of gypsum to obtain optimum resistance is probably still necessary.

Supersulfated cements

Supersulfated cements (SSC) consist of a blend of ground granulated blastfurnace slag (ggbs) and calcium sulfate (usually in the form of anhydrite) and are hydraulic binders. In contrast to common cements, the ggbs is mainly activated by calcium sulfate, although in order to accelerate the activation and early hydration of the slag up to 5% of other additional constituents may be added to maintain the pH of the system at optimum values.

A number of companies in Europe are now producing SCC at an industrial scale for use in concrete construction. However, there has been little independent research on the performance of these cements in aggressive environments and of the role and nature of the composition of the cements on the strength, deformation and durability characteristics of structural concrete.

Research within the Centre has investigated SSC at a fundamental level in order to optimise the reactivity of the constituents and proportion them effectively to provide appropriate levels of performance[3]. Furthermore, the research has used these laboratory-formed SSC combinations in concrete to determine the microstructural properties of SSC concrete and measure the engineering and durability properties. Industrially produced SSC has also been used as comparison.

In general, results have been promising and have shown that SSC concrete can achieve design strength requirements with eCO_2 emissions 78% and 64% lower than those of Portland cement and blastfurnace cement (III/A) concretes, respectively. Furthermore, for a given design strength, drying shrinkage will reduce and the

Figure 2: Observation of concretes made using SSC, blastfurnace cement and Portland cement after exposure to 5% Na_2SO_4 for 100 weeks (w/c ratio = 0.65)

concretes exhibit greater resistance to sulfate attack than Portland and blastfurnace cements (Figure 2).

However, because SSC produces concretes that have inherently low alkali reserves there are concerns with respect to the resistance of these concretes to carbonation. Indeed, accelerated carbonation tests show that these concretes lose alkalinity more rapidly than Portland composite cement concretes. Therefore, they are not normally marketed for use in environments that are particularly susceptible to carbonation. However, because of the very low eCO_2 of these cements, it is possible that equivalent resistance to carbonation as blastfurnace cement concretes can be achieved by using SSC at high cement contents and still obtain savings in eCO_2. However, the research has investigated the potential for using fillers to reduce the porosity and permeability of SSC concretes, thereby reducing the rate of carbonation.

Alkaline ash binders

Alkaline ash binders are alumino–silicate rich materials that are activated by an alkaline solution in the concrete mixer[4]. BRE has conducted a series of industrial precast concrete trials which demonstrate the successful adoption of alkaline ash binders[5,6]. The particular alumino-silicate rich material used in this research has been coal combustion fly ash. However, to ensure that the alkali-activation can take place at ambient temperatures, a novel approach has been to combine the fly ash with a small proportion (up to 10% by mass) of calcium-rich material, either ggbs or hydrated lime.

While similar technologies, in particular geopolymers, have been in existence for some years little work has been published on long-term durability of concretes made from alkaline ash binders. In particular, concern has been expressed in relation to alkali–silica reaction (ASR) because of the deliberate addition of large quantities of alkalis and the question of how these alkalis are bound within the resulting hydration products and within the pore water system. Research by the BRE Centre of Excellence for Innovative Construction Materials has been investigating this aspect of the durability of alkaline ash binder concretes in detail.

ASR occurs when certain aggregates react chemically with the alkalis present in the cement; the aggregates expand (or swell) resulting in cracks and disintegration of concrete. ASR is usually associated with siliceous rocks containing silica in a glassy (ie reactive) form, for example cherts, siliceous limestone and some volcanic rocks.

A total of 41 concretes were investigated as part of the study and the main parameters studied included:

- aggregate reactivity, using Cheddar limestone, Thames valley sand and gravel, Bally Barnes greywacke and coarse flint glass
- alkali activator capability through changes to sodium silicate content (41–97% by mass of solution) and NaO content of the solution (8–15% by mass of solution)
- the activator/binder ratio.

Portland cement concretes were cast using all four aggregates as control specimens.

Tests were carried out in accordance with the methodology described in RILEM AAR-3. Changes in length and mass have been monitored from day one until extreme deterioration was observed or an expansion of more than 0.05% was identified, which according to RILEM AAR-3 is detrimental if it happens before one year (Figure 3). Current observation of all prisms indicates that the alkaline ash binder concrete is performing better under ASR conditions than the Portland cement concrete (control) and to date (after 2.5 years) no alkaline ash binder concretes have shown signs of major expansion or cracking.

To confirm the absence of ASR gel, detailed analysis of the specimens has been undertaken in addition to an investigation into the change in pore solution pH during the early stages of hydration. This is because the presence of water-soluble alkalis within the concrete are associated with the occurrence of ASR. Initial analytical study of the water-soluble alkalis has found that most of the alkalis are bound in hydration products and this results in a substantial reduction in water-soluble alkali concentration as reactions proceed. However, the resulting water-soluble alkali content after 28 days is still high when compared with the profile of water-soluble alkalis within Portland cement concrete that is known to be susceptible to ASR. Consequently, further fundamental work is required to ascertain the reasons why ASR is not occurring and whether it is because there is insufficient calcium hydroxide present in alkaline ash binder concrete for the formation of expansive calcium alkali silicate products.

So far, the evidence is that the use of alkaline ash binders in concrete will not lead to ASR even when used in conditions favourable to ASR formation and with use of very reactive siliceous aggregates.

Figure 3: Measurement of expansion due to ASR

PROJECT OUTCOMES/CONCLUSIONS

The research has demonstrated the potential for using three cementitious systems that are inherently less CO_2-intensive than Portland cement:

- calcium sulfoaluminate cements
- supersulfated cements
- alkali-activated cements.

Based on both analytical investigation of the fundamental mechanisms by which these cements work and experimental research, it has been shown that these cements can be used to produce concrete suitable for use in UK conditions, and that these concretes have, in many cases, lower embodied CO_2 than current concretes.

RESEARCH OUTPUT

The research described above has been presented at a number of international conferences throughout the past three years[1–4] and in two BRE Information Papers[5,6]. Journal papers and two PhD theses are currently in preparation.

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ENERGY

DEVELOPING A PROCESS FOR IDENTIFYING OPPORTUNITIES FOR LOW-CARBON DISTRICT HEATING

Robin Wiltshire, Olaf Jangsten, Antonio Aguiló-Rullán and Jonathan Williams

Building Futures, BRE

SUMMARY

This project examined what techniques are being used internationally for low-carbon district heating. It produced a BRE Information Paper focusing on new-build developments, concluding that to be successful such developments must be of high density and should be open to emerging new techniques such as twin-pipe systems. The project pulled together the results of a survey into District Heating futures, in the form of a Roadmap report produced with support from the European Commission.

BACKGROUND

District heating (DH) is an enabling technology for many low carbon technologies. It comprises a pipe network connecting multiple heat demands to a central heat source (Figure 1). Technologies such as Combined Heat & Power (CHP) and biomass are better applied to the built environment through a heat network because the load sharing produces a smoother load profile that makes operation easier, more efficient and more consistent. Any local source of waste heat or low-carbon fuel can be integrated; heat networks confer fuel flexibility.

In the UK, however, DH remains at low penetration; the above issues are often dismissed or overlooked due to high capital cost and lack of necessary technical and organisational skills. However, this scenario is now shifting very rapidly: DH is suddenly being recognised by developers addressing the Code for Sustainable Homes[1] and obligations to integrate renewable energy technologies. With DH prominent within the London Plan, the GLA has an imperative for considering it as part of the planning process.

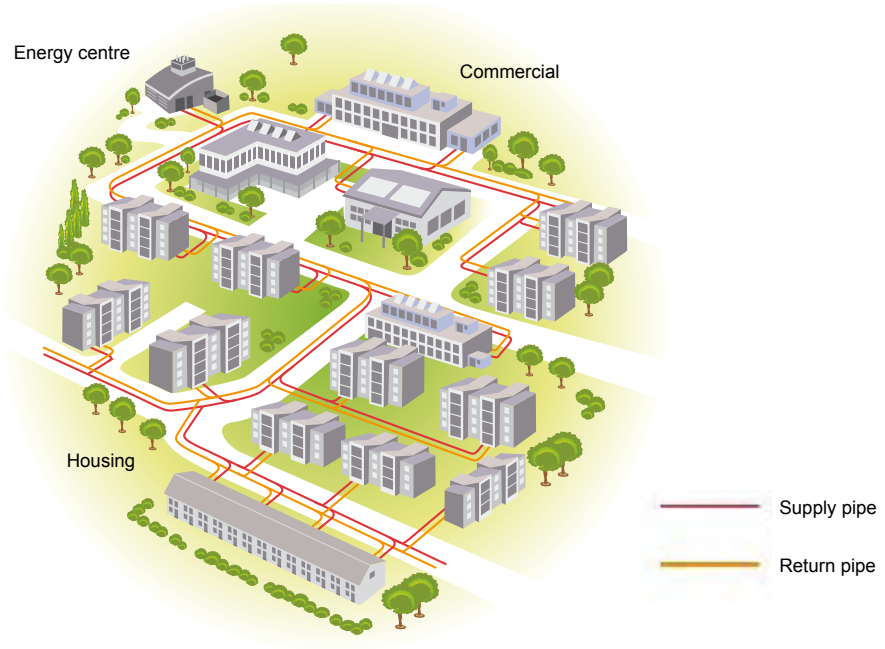

Figure 1: Schematic drawing of a district heating network

However, there is a need for caution as DH is best implemented where heat demand density is high; new developments with low heat demands and low density therefore present a much more difficult task. Many of BRE's strategy assessments, for private and public sector clients, now involve making a judgment about the DH heating option. As well as ensuring DH is implemented only when the heat density is high enough, there are also opportunities for innovation: including incorporation of renewables and use of twin-pipe systems.

RESEARCH PROGRAMME

The project consisted of:

- investigating new technologies and supportive policy instruments within the international DH field
- deducing applicability to the UK
- reporting when and how to develop DH in a BRE *Information Paper* and a European Commission project report.

PROJECT OUTCOMES/CONCLUSIONS

For new developments:

- *high-dwelling-density developments*, despite their lower heat demand, can be effectively served by well-designed DH schemes and will experience relatively small losses
- *low-dwelling-density developments* using single-pipe DH systems have heat distribution losses that can be unacceptably high.

Research has shown that when twin-pipe systems are used, heat distribution losses can be reduced by 20–30% compared with single-pipe systems (Figure 2). Heat distribution losses can also be reduced by using smaller pipes with local hot water storage.

Figure 2: Example of a heat distribution network: pre-insulated steel twin-pipe system

Roadmap for the UK

The Roadmap considers the large energy-saving potential of DH systems, particularly in high-density locations when individual building solutions are more difficult. It also points out that DH can play a useful balancing role in the move towards grid decarbonisation. It sets out over-arching goals and milestones that include:

- the development of core DH systems, which already exist in several cities, in most major cities by 2020–2050
- networks serving 'prosumer' (sometimes producer, sometimes consumer) buildings that integrate all forms of renewable heat and new heat-producing technologies by 2050.

It suggests ways in which various stakeholders, most importantly local authorities, can bring this about, provided that a more supportive regulatory structure can be devised.

RESEARCH OUTPUT

This research has been published in:

Jangsten O, Aguiló-Rullán A, Williams J and Wiltshire R. The performance of district heating in new developments: application guide. BRE IP 3/11. Bracknell, IHS BRE Press, 2011.

District heating roadmap for UK. Ecoheat 4eu project for the Intelligent Energy Europe Programme. Available as a pdf at http://ecoheat4.eu/en/Country-by-country-db/United-Kingdom/Road-Map-Report/

A BRE Trust report, *A technical guide to district heating*, will be published by IHS BRE Press in 2012.

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INTEGRATING PHOTOVOLTAIC TECHNOLOGIES INTO THE BUILT ENVIRONMENT

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SUMMARY
Recently, many thousands of PV systems have been fitted to buildings. Nearly all of these use frame-mounted, standard PV modules, which many regard as unsightly. This type of PV has the single function of generating electricity. By contrast, building-integrated (BIPV) systems, as well as offering the potential for an aesthetically pleasing appearance, can have multiple functions such as weather protection, solar shading, sound attenuation and integration with passive ventilation systems. By a combination of research into products and attitudes, and dissemination activities, this project has helped to inform the construction industry and connect it with the suppliers of BIPV technology.

BACKGROUND
Building-applied photovoltaic (BAPV) systems are the ones typically seen mounted on roofs of domestic buildings (Figure 1). There has recently been an explosion in popularity of these systems in the UK due to the introduction of initially generous feed-in tariff incentives. These systems are simple to retrofit and suitable for most buildings having an unshaded, roughly south-facing roof, but they have no function other than to generate electricity. Also, their appearance is rarely sympathetic to the building's appearance.

Building-integrated photovoltaic (BIPV) modules, on the other hand, form part of the building covering which immediately opens up other possibilities (Figure 2). All PV systems generate electricity, but BIPV installations have the potential to be multi-functional, providing:

- weathertightness
- electricity generation
- solar shading
- thermal insulation
- ambient noise reduction
- electromagnetic shielding
- heat for passive ventilation and pre-warming for heating systems

These functions can all contribute to the value added by the BIPV system, but the other factor that can be of high importance for architects is that, through imaginative design, BIPV can enhance the aesthetic appeal of a building.

BIPV systems are not as easy to categorise as BAPV arrays as there are several fundamentally different types; in approximate order of increasing cost, these are:

Figure 1: Typical retrofitted BAPV array

- PV roofing membranes (which can be classified as BIPV if they provide weathertightness)
- general-purpose PV modules used within a BIPV mounting system
- PV tiles or shingles
- purpose-designed BIPV modules for roofs, façades or windows
- bespoke modules of differing sizes and shapes on the same building

RESEARCH PROGRAMME
This project has:

- documented the current status of BIPV products in the UK
- characterised the attitudes of architects towards BIPV.

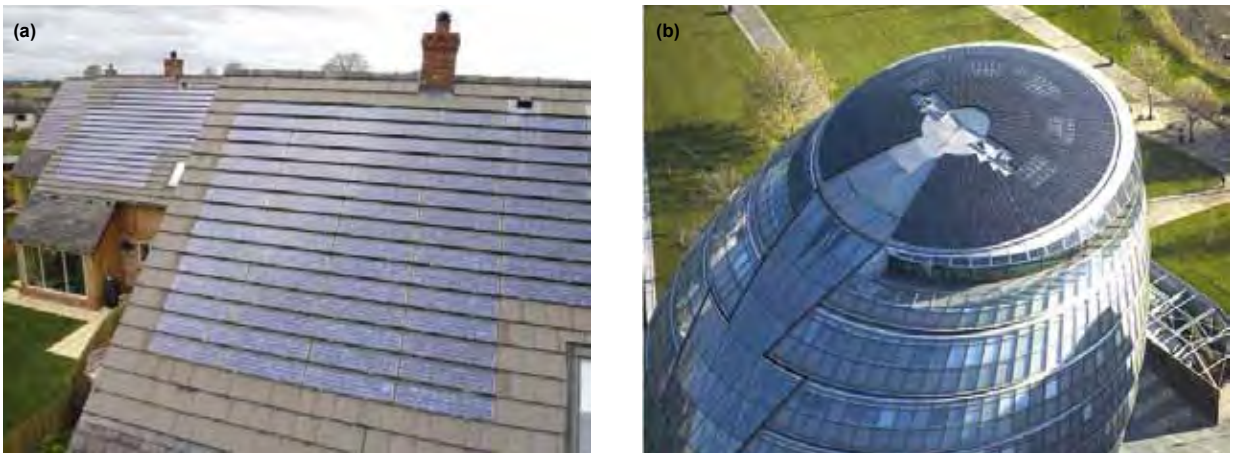

Figure 2: Examples of BIPV installations: (a) BIPV tiles integrated with tiled roofs. Courtesy of Sundog Energy; (b) Bespoke glass–glass laminate BIPV modules on the roof of City Hall, London. Courtesy of Romag

Several methods have been used to gather the information, including:

- a survey of products currently on the market
- a survey of architects
- two stakeholder workshops.

The components of the project were to:

- review buildings-integration issues
- survey existing BIPV products
- produce a product gap analysis
- conduct a stakeholder workshop: BIPV futures
- produce a financial analysis of BIPV systems
- investigate BIPV for retrofit
- conduct a stakeholder workshop: Product design improvement potential
- summarise the requirements for BIPV products in the UK.

PROJECT OUTCOMES/CONCLUSIONS

Our consultation with manufacturers, practising architects, engineers, installers and potential 'green clients' through this project has provided good information on some of the barriers perceived by building designers and PV system designers and installers.

Many products are already available today, and the cost of these is reducing rapidly. Implementation costs are also reducing as manufacturers become more attuned to the demands of the construction industry and as the 'usability' of product designs improves.

The skills required to design and install BIPV are quite rare within the construction sector so specialist installers are currently filling this niche. However, as time goes on, we can expect more of these skills to be absorbed by existing trades, such as site electricians and roofers, so costs can be expected to reduce even further.

The key messages for manufacturers emerging from feedback from potential users of BIPV products are summed up in the following list of requirements and wishes:

- better information on:
  - cost, benefit and performance data
  - durability and product life (actual durability and warranty information)
  - case study examples
  - technical and design information
  - 'how-to-specify' guides
- better consistency of information to allow comparison of products
- more choice of colours and surface textures would be desirable
- improvements in energy performance/efficiency
- better access to products available in other countries
- cost reductions.

Although several types of BIPV system are already being successfully used in refurbishment projects, a major challenge for BIPV manufacturers is to design products that can be economically retrofitted to limited areas of roof or façade coverings before their natural end-of-life. If BIPV systems can become more economical via product cost reductions, better information for specifiers and, perhaps initially, a special feed-in tariff rate, the prize for suppliers and installers will be large indeed owing to the potential market size.

The public benefit would be the potential to reduce carbon emissions by generating electricity locally while maintaining, or even enhancing, the visual appeal of buildings and avoiding the unsightly appearance of some BAPV systems.

RESEARCH OUTPUT

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USING RENEWABLE ENERGY IN DISTRICT HEATING NETWORKS

Akshay Gupta and Robin Wiltshire

Building Futures, BRE

SUMMARY

District heating is an important enabling technology for reducing carbon emissions, assisting security of energy supply and conserving fossil fuels. Potential fuel choices include renewable energy technologies: biomass, solar thermal and geothermal energy. This project investigated the inclusion of renewable heat technologies in district heating networks.

BACKGROUND

District heating (DH) is increasingly recognised within the UK as a key enabling technology for:

- reducing carbon emissions
- assisting security of the energy supply
- conserving fossil fuels.

Thus, UK Energy Minister Greg Barker concluded (29 November 2011):
'our emerging analysis points to a more significant role for district heating in the UK'.

The UK Government's Infrastructure Plan (paragraphs 2.70 and 2.71) duly states that up to 50% of the UK's heat demand is found in areas where heat networks are potentially viable, and that district heating therefore offers a valuable alternative to building level heating as a means of decarbonising the UK's heat supply.

Most commonly, district heating schemes in the UK are built up by connecting a few buildings with relatively high heat demands, and supplying them with heat from a Combined Heat & Power (CHP) engine, running on natural gas. Although CHP engines do use fossil fuels sparingly, an even more attractive solution would be to use low- or no carbon sources. This is exemplified by the harnessing of renewable heat sources, including biomass, solar thermal and geothermal energy.

RESEARCH PROGRAMME

The project identified examples of renewable heat technologies that have been integrated into DH schemes in the UK and other European countries to determine how widespread is the use of renewable heat sources. The schemes were contacted to find out how successful they have been at integrating renewable heat sources. In addition, there was a discussion with the energy manager at the Greenwatt Way pilot scheme in Slough where several renewable technologies are linked in a mini-DH grid.

PROJECT OUTCOMES

The main outcome was to discover that integration of renewable heat is much less prevalent than its potential would suggest. A statement from an influential Technology Platform for District Heating, comprising experts from mature district heating countries, concluded that this area requires further research, and that the potential primary energy savings and carbon emission reductions are large. Nevertheless, there were some interesting insights into schemes which have successfully integrated renewable heat technologies.

Individual renewable heat technologies

Biomass

Biomass is a carbon-neutral renewable energy resource because carbon absorbed during growth is equivalent to the carbon emitted when burnt. Biomass can be used either through direct or indirect combustion, the latter through gasification or anaerobic decomposition to produce methane as the primary product. For indirect combustion, after the biomass has been converted to useful gas, the gas can be used in any conventional boiler. Biomass can also be used as a fuel for CHP systems.

Solar thermal

The integration of solar thermal collectors into a district heating network means that, instead of being used directly at the individual building level, the heat is supplied to the district heating system either via the network itself or to a storage vessel. Collectors may be situated on the buildings themselves or in a 'solar field'. Large ground-mounted solar thermal fields serve the DH networks in Hillerod and Marstal in Denmark where they serve up to 55% of the total heat demand.

Geothermal

Aquifers deep down in the earth (typically 1500 m or more) contain water at a relatively high temperature (both temperature and depth are site-specific). This resource can be exploited by pumping up the water either in an open loop or via a closed loop system. It may be necessary to add a heat pump if the temperature of the geothermal water is below the temperature required for the DH system.

While exploitation of this resource is limited to areas with geothermal aquifers, the global potential is high with, for example, Denmark (a country with a high penetration of district heating) estimating that sufficient heat exists to supply their DH systems for several thousand years!

By using a heat pump, geothermal energy can also be extracted even from shallow depths directly beneath the ground. Heat pumps are effective at converting nearly constant low temperature sources into useful DH sources.

While the ground is the most common heat sink for heat pumps (in the UK 10–12 °C is the typical ground temperature), this is most commonly used for single building applications. Large-scale heat pumps that can be integrated with DH systems include as their heat source:

- deep lake or even sea water
- sewage water
- geothermal waters arising in disused mines.

In general, the best circumstance is for low temperature DH networks so that the required temperature elevation is small, leading to a higher coefficient of performance. The possibility also exists for fully renewable energy heat pump systems where renewable electricity powers the heat pump.

RESEARCH OUTPUT

A BRE Information Paper will be published by IHS BRE Press in 2012/13.

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BRE CENTRE OF EXCELLENCE IN ENERGY UTILISATION, UNIVERSITY OF STRATHCLYDE

John Counsell

Professor, Energy Systems Research Unit

The BRE Centre of Excellence in Energy Utilisation at the University of Strathclyde has been established as an integral part of the Energy Systems Research Unit (ESRU) which has over 30 years' experience in modelling, simulating and designing advanced energy systems for the built environment and renewable power generation. ESRU has five full-time academic members of staff, including the BRE Centre of Excellence Director, Professor John Counsell. The Centre has nine PhD students and two research associates receiving part-funded scholarship funds from the BRE Trust, BRE, Arup and Barr.

In addition to the platform research of the PhD projects described in the papers that follow, the Centre has built up a critical mass of knowledge exchange with the building services and building manufacturing industries. Example projects are:

- A Technology Strategy Board-funded project BIEN-RPG to develop innovative smart DC IT networks. This has resulted in a collaboration agreement for exploitation with the University of Strathclyde which is also investigating international-scale impact through collaboration with India's IIT Bombay.
- A £1m project from the Engineering Physical Sciences Research Council (EPSRC) post-doctorate secondment working with BRE Scotland and Arup in the application of BIEN technologies and the use of pervasive sensor networks for building monitoring and systems control. This project is being carried out in partnership with the University of Newcastle.
- Private company investment such as a control system development with Gencoa Ltd to develop new manufacturing processes for organic light-emitting diode (OLED) screens on mobile phones, computer displays and TVs that could bring about huge energy efficiency gains worldwide in the next five years.

This year, the Centre completed a highly successful a Knowledge Transfer Partnerships (KTP) programme to facilitate knowledge exchange of the research results with the manufacturing industry, the first programme established being with Barr Ltd. This has resulted in continued research funding for a Research Assistant to work at Barr through the duration of the EPSRC Knowledge Transfer Accounts (KTA) programme. The Centre has now filed patents in the automatic control of carbon emissions from appliances controlled via in-building networks. This will lead to a potential spin-out company being formed in 2012 as a joint partnership between BRE Ventures and the University of Strathclyde. Further, BRE Ventures has supported a KTA award for the BRE PhD student, Matthew Stewart, whose project was presented in the *BRE Trust Review 2009*.

2nd International Conference on Microgeneration and Related Technologies (Microgen 'II) was hosted by the University of Strathclyde, 4–6 April 2011 and sponsored by BRE Trust

The core platform of PhD projects for the next decade follow the key research themes in energy utilisation:

- Advanced building regulation Compliance Tools (ACTs) for conceptual design of buildings and their energy systems and building regulation compliance.
- Advanced control of energy systems (ACES) projects that aim to transfer leading-edge knowledge and control solutions from other fields such as aerospace and automotive systems into building controls.
- Digital energy networks (DENs) projects that explore full integration, smart grids, building-integrated renewable power sources and intelligent appliance networks with energy storage for energy demand reduction and electricity load management. Professor John Counsell was appointed as the Chairman of TSB's Smart DC Special Interest Group which will raise a call for proposals which fit within the scope of DENs.

The projects draw on the core research science and software tools of the ESRU Group of which the BRE Centre of Excellence is an integral part. The papers that follow provide an overview of final-year projects.

For further information on any of the projects that follow, contact Professor John Counsell,
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INVERSE DYNAMICS BASED ENERGY ASSESSMENT AND SIMULATION

Gavin Murphy

BRE Centre of Excellence in Energy Utilisation, University of Strathclyde

SUMMARY

This project has developed a new Standard Assessment Procedure (SAP)-compliant advanced dynamic simulation method (IDEAS – Inverse Dynamics based Energy Assessment and Simulation), which can be used in the energy modelling of dwellings. The purpose of the IDEAS method is to suggest where advanced controllability of dwellings and a dynamic framework could supplement SAP. The IDEAS calculation method is based on current SAP parameters to produce a simple-to-use method which is familiar to users of SAP.

BACKGROUND

The Standard Assessment Procedure (SAP) is the UK Government's approved methodology for assessing the energy ratings of dwellings. SAP is a calculation method based on empirical relations from measured data. A yearly calculation was used in SAP until the release of SAP 2009[1], which employs monthly calculations. SAP has moved from using a large time step with a coarse time resolution to a smaller time step with a medium time resolution.

Rising carbon dioxide emissions from dwellings advocate that properties designed using sustainable methods will become commonplace in the future. In tandem with enhanced sustainability, dwellings will increasingly be designed to generate renewable energy. SAP's modelling of renewables has been highlighted as an area which could benefit from additional research. Modelling future complex dwellings and systems will require an advanced calculation method which is capable of more detailed modelling and simulation. Using a smaller time step which is measured in minutes and not months will produce results that allow more detailed analysis of energy performance.

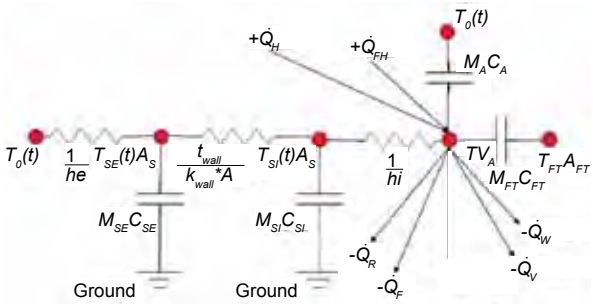
Dynamic simulation methods (DSMs) already exist which can operate at a small time step. However, with DSMs it is difficult to make a comparison with SAP as the temperatures used in SAP are not well understood. To calculate energy consumption, the SAP methodology guarantees that a standard occupancy temperature profile is met perfectly. A dynamic method which also guarantees the SAP standard occupancy temperature profile is required. This is difficult in complex DSMs as their control algorithms are often inadequate to optimise the heating system to guarantee that a temperature is met perfectly.

RESEARCH PROGRAMME

The IDEAS tool was developed by going back to first principles for the modelling philosophies of BREDEM and full dynamic simulation tools such as TRANSYS and ESPr. Having established the fundamental assumptions and modelling techniques used in these tools, a simplified symbolic thermodynamic model for a house was created. This simplified model, with significantly reduced numbers of parameters compared with full dynamic simulation tools, allows the application of inverse dynamics theories developed in the aerospace and robotics industry to be applied. Use of this method enabled calibration and comparisons of energy estimation with tools such as SAP and Passive House Planning Package (PHPP). Moreover, the symbolic tool allowed sensitivity and calibration studies to be carried out to establish credible values of important parameters which have uncertain values in practice. These values could be tuned to calibrate the model against the baseline of BREDEM which is based on real house performance data. Thus, the IDEAS tool provides a simplified thermodynamic model of homes, calibrated using real house data. This gives the IDEAS tool the potential to provide a more detailed calculation methodology for building regulation compliance tools, controller design tools and house design tools for use by small to medium architecture businesses.

PROJECT OUTCOMES/CONCLUSIONS

A novel SAP-compliant advanced dynamic calculation method (IDEAS) has been developed which guarantees that the SAP standard occupancy temperature profile is perfectly tracked and is also calibrated with SAP. The Inverse Dynamics-based Energy Assessment and Simulation (IDEAS) method employs the perfect inverse control law, ie robust inverse dynamic estimation (RIDE) to guarantee that the SAP standard occupancy temperature profile is met. IDEAS produces SAP-



Key:

A = Area
A_{FT} = Area (furniture and internal mass) (m^2)
A_S = Area (structure) (m^2)
C_A = Specific heat capacity (air) (J/kg.K)
C_{FT} = Specific heat capacity (furniture and internal mass) (J/kg.K)
C_{SE} = Specific heat capacity external (structure) (J/kg.K)
C_{SI} = Specific heat capacity internal (structure) (J/kg.K)
he = Convective heat transfer coefficient external (W/m^2K)
hi = Convective heat transfer coefficient internal (W/m^2K)
k_{wall} = Thermal conductivity of wall (W/m.K)
M_A = Mass (air) (Kg)
M_{FT} = Mass (furniture and internal mass) (Kg)
M_{SI} = Mass (internal structure, used in 4th order model) (Kg)
M_{SE} = Mass (external structure, used in 4th order model) (Kg)
$\dot{Q}_F$ = Heat transfer through floor (W)
$\dot{Q}_{FH}$ = Heat transfer from free heat (W)
$\dot{Q}_H$ = Heat transfer from heating (W)
$\dot{Q}_R$ = Heat transfer through roof (W)
$\dot{Q}_V$ = Heat transfer through ventilation (W)
$\dot{Q}_W$ = Heat transfer through windows (W)
T = Internal temperature (K)
T_0 = Outside temperature (K)
T_{FT} = Temperature (furniture and internal mass) (K)
T_{SE} = External temperature (K)
T_{SI} = Internal structure temperature (K)
t_{wall} = Thickness of wall (m)
t = time (seconds)
V_A = Volume (air) (m^3)

Figure 1: An electric circuit equivalent of the IDEAS thermodynamic mathematical model

compliant results and allows confident (ie calibrated in SAP) predictions to be made regarding the impact of novel heating and renewable energy systems.

The temperatures used in SAP have been researched in depth and an analysis of the implications of tracking air temperature and various comfort temperatures is given. A focused evaluation of the treatment of renewables in SAP and DSMs is also presented, leading to suggestions that have been implemented in the SAP framework. The role of real-life monitoring in the energy assessment process is highlighted together with the monitored studies. Case studies applying IDEAS to buildings with renewable heating systems are described.

The philosophy, research and equations derived in IDEAS are presented in this project demonstrating their use in Microsoft Excel and Matlab/Simulink environments. The IDEAS method:

- employs SAP as an exemplar steady-state calculation to highlight the successful use and calibration of a new advanced inverse dynamics-based symbolic method
- is transparent and portable
- can be applied to other methodologies, such as those employed by the Passive house design package (PHPP) and simplified building energy model (SBEM)[2] (by carrying out a calibration process), and also to different simulation environments such as ESP-r and ESL (by adopting the IDEAS equations in those methods)
- has many uses outwith SAP which are highlighted in the cases studies.

The contribution to knowledge of IDEAS is demonstrated in this project by the development of the method and the use of SAP as a comparator.

Figure 1 highlights an electrical circuit equivalent of the IDEAS model, where the main variables required for advanced controllability analysis and calculating the energy modelling of dwellings are shown. Figure 2 demonstrates a comparison of IDEAS and BREDEM (SAP) between comfort, temperature and energy consumption — IDEAS has been calibrated with BREDEM over a wide range of test cases. Figure 3 highlights the development of an optimum start algorithm into IDEAS — this is required so that a slowly responding heating system can meet a demanded setpoint in time. This functionality is an extension to steady-state methods and can also be used to help with sizing heating systems appropriately and analysing their transient response.

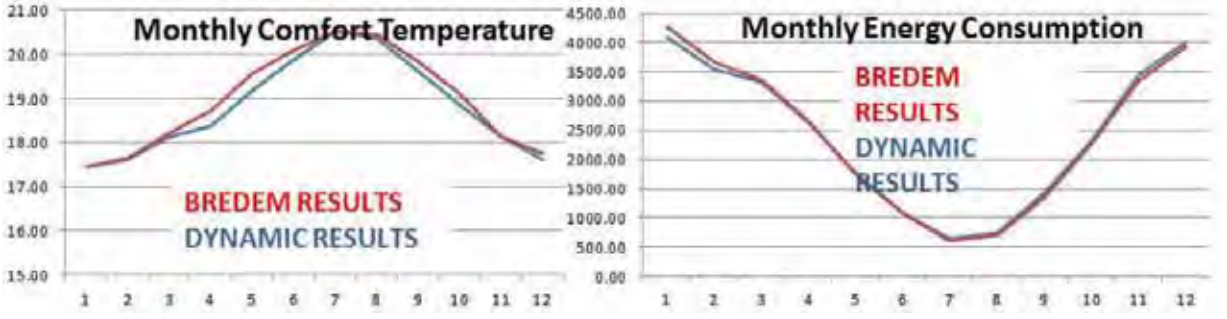


Figure 2: Sample output from IDEAS project

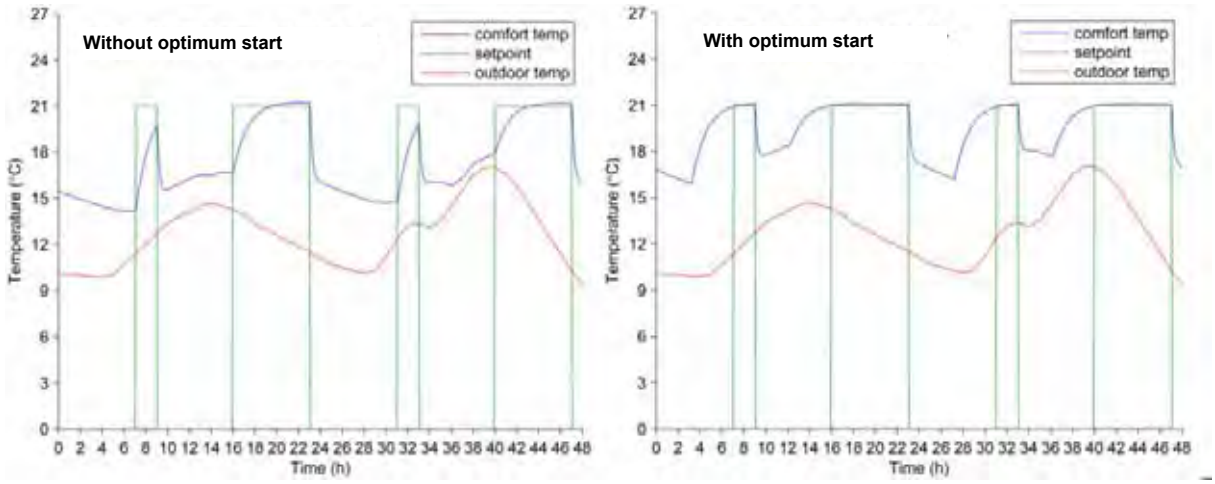


Figure 3: Demonstration of optimum start implementation in IDEAS

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ADVANCED NON-LINEAR CONTROL FOR AEROSPACE AND ENERGY SYSTEMS

Joseph Brindley

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SUMMARY

This project bridges the gap between advanced control systems design in the aerospace industry and current control systems design in the buildings industry. Its main contribution is to show that high-performance control system design can be successfully deployed in buildings in a similar way to that of aircraft. Novel high-performance control algorithms were designed for use first in aerospace and then were successfully transferred to building controls for heating and air-conditioning. Simulations of a heating, ventilation and air-conditioning system demonstrated that the advanced control algorithms were able to provide more accurate and robust control of air temperature and humidity compared with a traditional controller design. The simulations demonstrated the potential impact of advanced control on reduction in energy consumption (and consequent reduction in energy bills and carbon dioxide emissions) especially in highly insulated and air-tight buildings.

BACKGROUND

Building systems involve control problems which are highly complex and non-linear. The control system (Figure 1) is often required to accurately track multiple, coupled variables (eg internal air temperature, relative humidity, carbon dioxide and luminescence) in the presence of many disturbances, and with actuator systems which have severe power limitations. If the control system is not designed to meet these challenges, performance of the system can be reduced resulting in undesirable behaviour, such as large temperature overshoots and excessive energy usage. This project aims to improve the performance of a building's control systems by utilising controller design methods originally developed for high-performance flight control systems. Improving the control system can bring about benefits in energy efficiency and quality of performance through far more accurate control. The project provides a knowledge-exchange activity to apply these techniques to building energy management systems (BEMS).

RESEARCH PROGRAMME

The novel nonlinear controller design method of rate-actuated inverse dynamics (RAID) was developed using state-of-the-art nonlinear inverse dynamics (NID) as a foundation. This controller design was used in the development of a high-performance flight control system in order to provide accurate and simultaneous control of

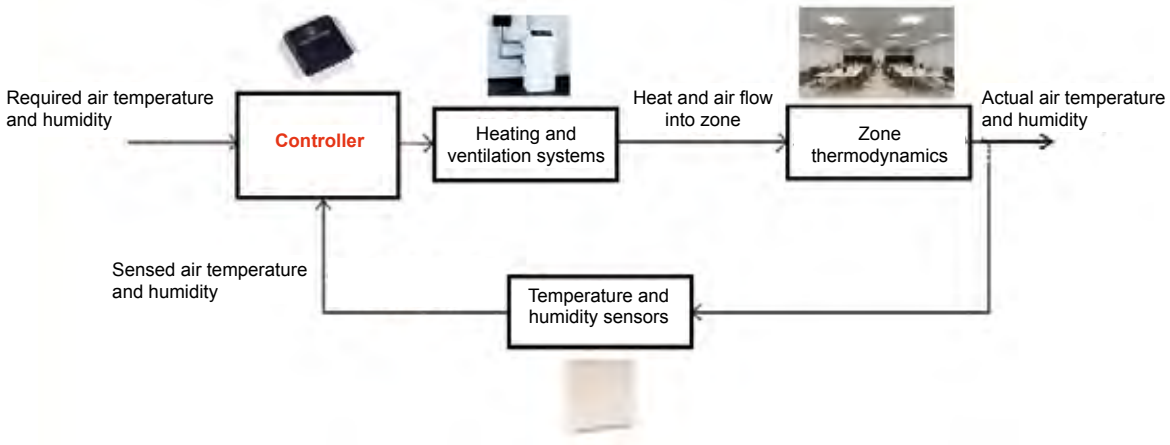

Figure 1: Diagram of a building's feedback control system

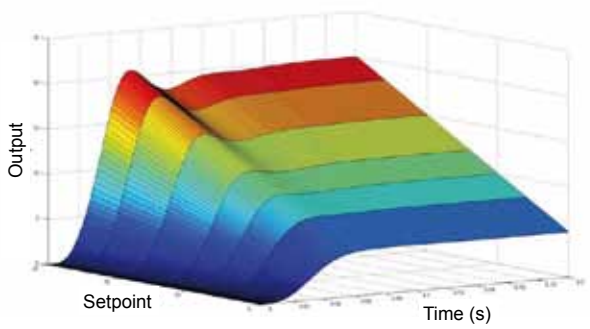

Figure 2: Output and input relationship of dynamic variable transient response (VTR)

multiple variables. This type of controller design method was identified as being capable of enabling better control of heating, ventilation and air conditioning (HVAC) systems compared with more basic traditional controller designs. Using RAID controller design methods, an advanced HVAC controller was developed with the aim of reducing setpoint overshoot and interaction between the controlled variables of internal air temperature and humidity. The importance of control robustness in the presence of building parameter variations, slow actuators and sensors led to the development of the controller design method of variable transient response (VTR). In conjunction with the RAID controller, VTR minimises any negative effects on control performance caused by building parameter variations and slow actuators and sensors. This is achieved by dynamically varying the responsivity of the system during the controller's operation (Figure 2).

A simulation of the RAID controller in a high-performance flight control application was conducted. The significant improvement in controller performance of the RAID design compared with a more traditional controller demonstrated its value in the field of high-performance flight control as well as highlighting the potential for its use in HVAC control. Following this case study, a simulation of an HVAC system in a climate-adaptive building was developed to test the performance of the RAID/VTR controller in the control of internal air temperature and humidity. The simulation results demonstrated reduced interaction between temperature and humidity and reduced setpoint overshoot when using RAID compared with a traditional proportional–integral–derivative (PID) design. With the addition of VTR, the robustness of the controller when subjected to sensor time delays was greatly increased (Figures 3 and 4).

The practicality of these controller designs for industrial applications was demonstrated after they were successfully implemented in the control of an industrial plasma-coating process used in the manufacture of low-emissivity glass and PV panels.

PROJECT OUTCOMES/CONCLUSIONS

The improved accuracy and response time of the developed advanced controller designs was estimated to save up to 10% in energy consumption. This will both improve the energy certification of the building and also improve the thermal comfort of the occupants. Thermal comfort has proved to be problematic in this type of building when employing traditional control methods such as PID control[1]. Furthermore, the design process

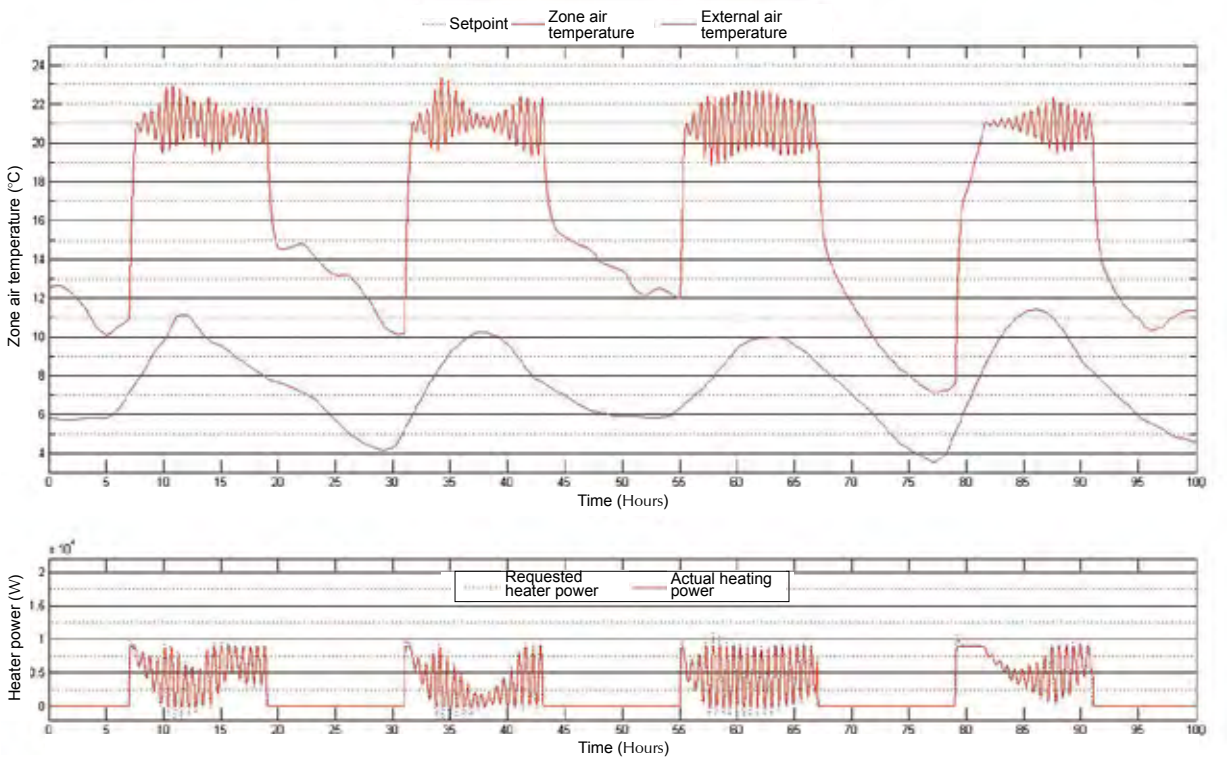

Figure 3: Heating, ventilation and air conditioning (HVAC) system under RIDE control

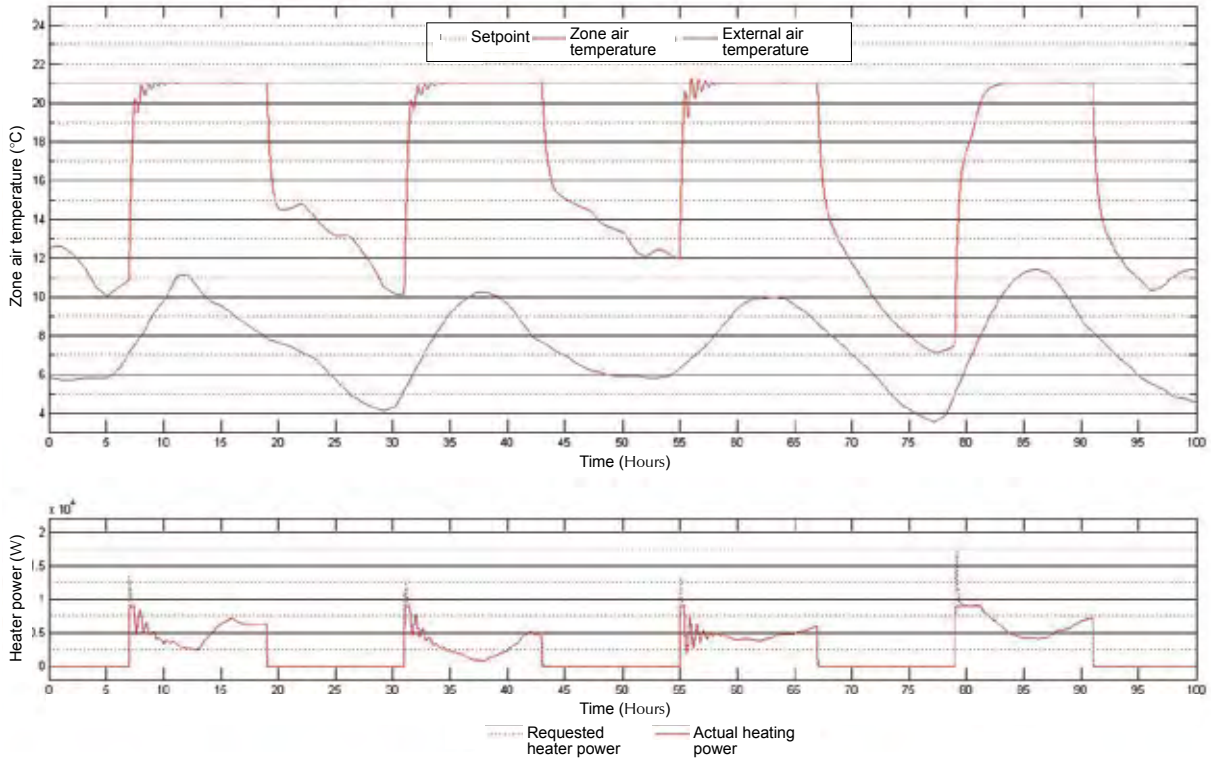

Figure 4: Heating, ventilation and air conditioning (HVAC) system under VTR control

and implementation of such controller designs was shown to require only a minimal increase in building information compared with a traditional PID design.

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SMART DC BUILDINGS AND THE DEVELOPMENT OF DIGITAL ENERGY NETWORKS

James Johnston

BRE Centre of Excellence in Energy Utilisation, University of Strathclyde

SUMMARY

This research programme has delivered a holistic study of the opportunity for buildings to use resources intelligently to minimise cost and carbon footprint. The programme looked at:

- the impact of digital technology trends on total energy consumption in offices
- the role of asynchronous DC power networks in the efficient integration of distributed energy resources such as batteries and solar photovoltaic systems.

BACKGROUND

Alternating current (AC) power distribution using analogue control and safety devices has been the dominant process of power distribution within our buildings since the electricity industry began in the late 19th century. However, with advances in digital technology, the seeds of change have been developing over the past decade. Now, with the simultaneous dramatic fall in power requirements of digital devices and corresponding rise in capability of Power over Ethernet, an entire desktop environment can be powered by a single direct current (DC) ethernet cable.

Going beyond this, it will soon be possible to power entire office buildings using DC networks. This means that the logic of 'one-size fits all' from the existing AC system is no longer relevant and instead there is an opportunity to redesign the power topology to be appropriate for different applications, devices and end-users throughout the building.

DC power distribution signals the first steps towards an overhaul in the way power is transmitted around a building. In particular, the research program has investigated the potential convergence between the consumer product-driven IT industry and the traditional utility-led electricity industry.

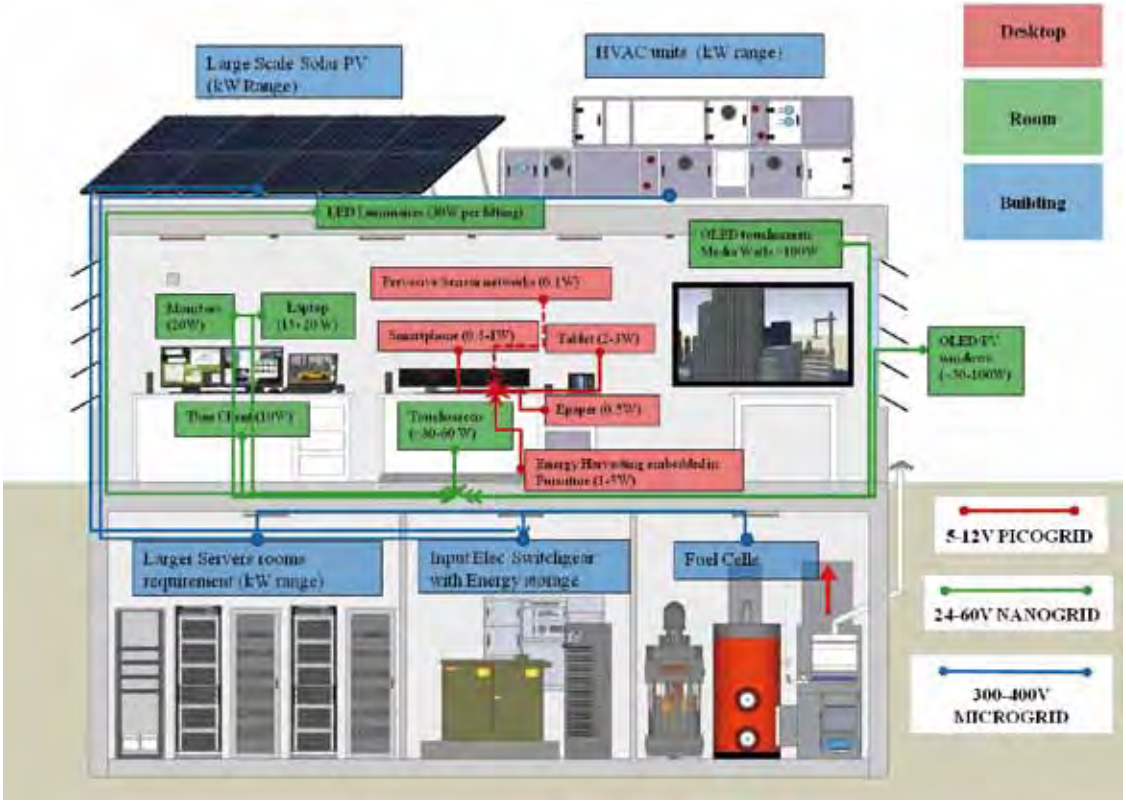

Figure 1: Overview of digital energy networks

This research has investigated the added value that an asynchronous DC network can offer, in particular:

- the opportunities for integrating predictive optimisation techniques for:
  - energy storage
  - solar PV
  - time of use battery systems
- developing the concept of a building-integrated smart grid.

RESEARCH PROGRAMME

The three-year research programme was carried out in conjunction with Arup. This close integration with practising engineers has helped to focus the research on real and pertinent issues, such as looking at the role of standardisation in the industry. The project has been part of the DC building initiative within Arup and has helped teams to make their designs futureproof by raising awareness of digital technology and global trends in distributed generation.

The project has also been conducted in collaboration with major DC power manufacturers across the world, from Moixa Energy (based in London) to DC Flexgrid (based in Pennsylvania), and EMerge Alliance and Redwood Systems (both based in California). In addition, considerable momentum has been built up towards looking beyond 'going-DC' and focusing on the added value of building-integrated smart grids.

PROJECT OUTCOMES/CONCLUSIONS

Direct research output includes:

- developing a simulation procedure for analysing the impact that trends in digital technology will have on the holistic energy consumption of offices
- developing a 3-tier classification system for the topology of DC microgrids in commercial buildings, ie a digital energy network (see Figure 1):
  - the first tier is power distribution at a full building level (known as the microgrid)
  - the second tier is power distribution at a room level (the nanogrid)
  - the third tier is power distribution at a desktop or appliance level (the picogrid)
- developing an optimisation strategy for a DC building with integrated renewables, battery storage and time of use electricity tariff (Figure 2 shows a sample output of the digital energy networks optimisation process).

As demonstrated at the CIBSE Technical Symposium in 2011, a key developing strategy is for much closer integration between the design and operation of buildings:

- first, from a heating/cooling perspective: as buildings are designed to be more airtight, there should be greater interaction between information and communications technology acquisition decisions and the design of heating/cooling systems
- secondly, from an electrical engineering perspective, an asynchronous DC microgrid should be developed

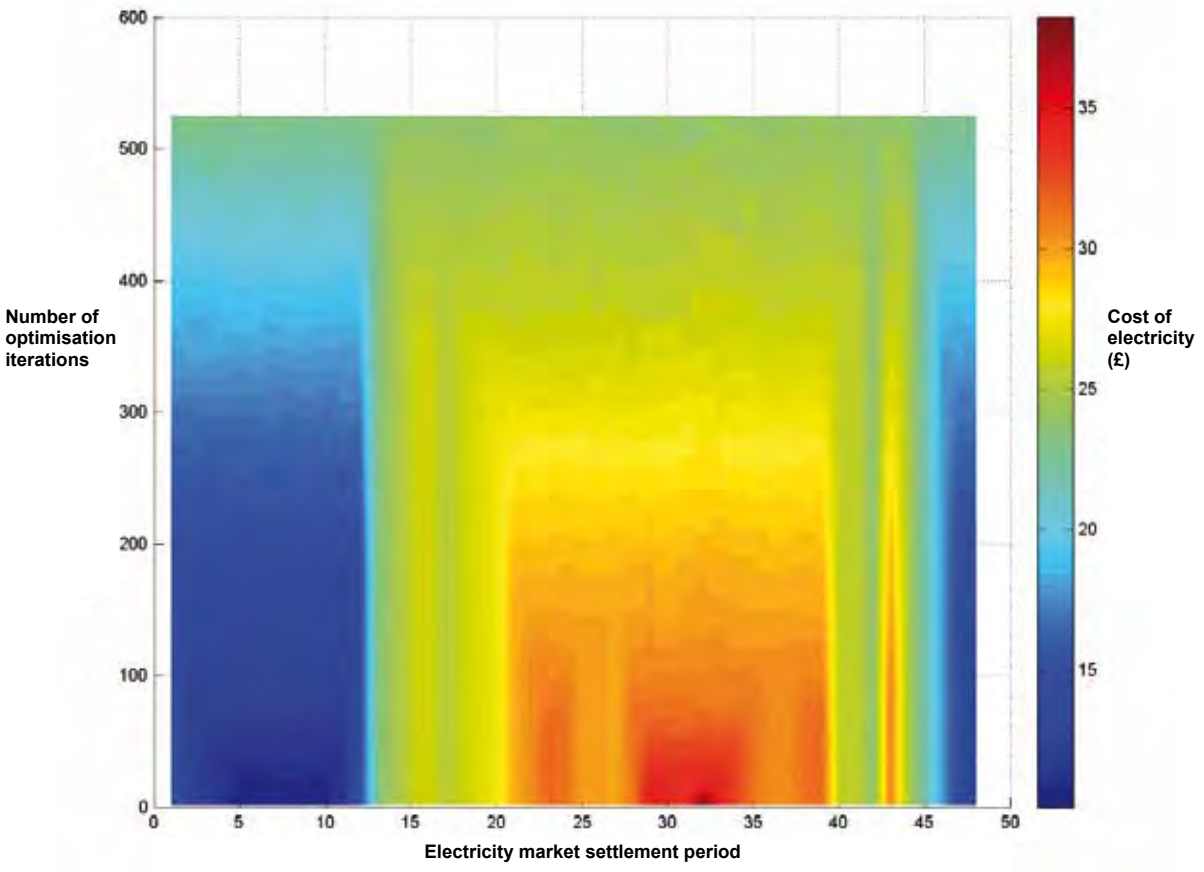

Figure 2: Sample output of the digital energy networks optimisation

where the focus for design can be optimising systems for occupants, rather than for utilities companies.

A key parameter required to initiate these changes is higher resolution of data capture of all energy-producing/consuming devices in the building. Only then can this concept of a building-integrated smart grid be implemented.

PUBLICATIONS/RESEARCH OUTPUT

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DEVELOPMENT OF ROBUST HIGH-PERFORMANCE CONTROLLER DESIGN METHODOLOGIES FOR BUILDING ENERGY MANAGEMENT SYSTEMS

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SUMMARY

A building's energy efficiency can be significantly improved if high-performance control systems are used as a replacement for the simpler control systems commonly in use in the building industry. High-performance control systems, however, require full knowledge of the system's physics and therefore cannot be effectively applied to buildings due to large parameter uncertainties. This project aims to develop methods which allow high-performance BEMS to be designed without full knowledge of the system's physics.

BACKGROUND

The dynamic and uncertain nature of buildings means that designing an effective building energy management system (BEMS) is by no means a trivial task. The control systems currently in use in the buildings industry, however, tend to be basic in their design and hence are often incapable of effectively controlling the building's systems under varying conditions. This leads to poor energy management and consequently high carbon emissions as well as poor thermal comfort for occupants. Hence, there is a need to develop advanced building control systems which can overcome these issues.

Advanced control systems, typically used in the aerospace and automotive industries, have robust designs meaning they can provide accurate setpoint tracking and quick response even when they are subjected to disturbances. In the case of HVAC control, disturbances are uncontrolled effects such as external temperature and radiation. Designing advanced control systems, however, requires the development of a mathematical model of the system's physics. Obtaining accurate models of buildings can be difficult since in reality the nature of their parameters (eg heat transfer coefficients and furniture surface areas) is uncertain. This means that normally advanced control methods cannot be easily or effectively applied to buildings.

This project aims to develop methods which allow high-performance control systems to be designed without full knowledge of the system's physics. These methods will then be used for the development of high-performance BEMS.

RESEARCH PROGRAMME

Method 1

A novel nonlinear multi-input multi-output (MIMO) controller design has been developed using advanced nonlinear inverse dynamics (NID) and evolutionary optimisation for relative humidity and room temperature control.

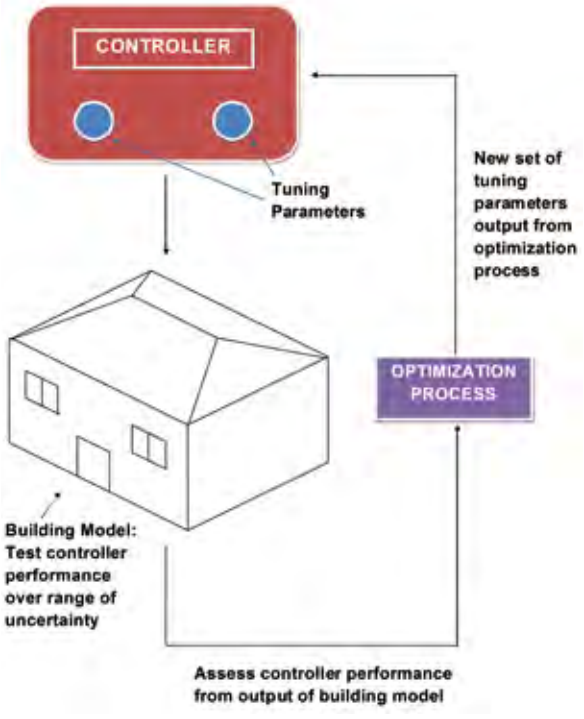

Figure 1: Schematic of controller design methodology for BEMS

The state-of-the-art NID method provides the basis for the control system to achieve fast, accurate and stable setpoint tracking as well as good disturbance rejection. This controller, however, has tuning parameters which are designed for optimum performance based on an accurate mathematical model of the system. This poses a problem in practice due to the uncertainty associated with the building parameters as mentioned in *Background*.

The developed method alleviates this problem by considering that an uncertain building parameter can be assumed to lie within a given range. An advanced optimisation technique is then employed to select the controller's tuning parameters such that it performs optimally without performance degradation, regardless of where the parameter actually lies within that range. In this way, the controller is made robust against the uncertainty in the mathematical model of the system. The controller design methodology is illustrated conceptually in Figure 1.

The performance of this developed controller design was evaluated through application to a nonlinear MIMO single-zone dynamic building model.

Method 2

Currently, research is being carried out using the abovementioned techniques in order to develop an online adaptive control system which continually optimises the controller performance. The method identifies the system's input–output relationship while continually altering the control system's transient response characteristics, shaping the system's response for optimum performance. Therefore, in a building control system, factors such as sensor placement, which have a severe effect on the performance of traditional controller designs, are no longer problematic as this adaptive control algorithm should account for the system's dynamics including the sensor time delay.

PROJECT OUTCOMES/CONCLUSIONS

Method 1

The proposed controller produced superior performance compared with a traditional proportional–integral–derivative (PID) controller design commonly used in the construction industry as well as the same NID controller optimised with a simpler optimisation algorithm. An improved level of thermal comfort is achieved, due to fast and accurate tracking of the setpoints, and energy consumption is shown to be reduced, which in turn means carbon emissions are reduced. This is demonstrated in Figure 2 which shows tracking of comfort temperature of all three control strategies over a four-day period.

The proposed controller also demonstrated good disturbance rejection when tested with the disturbance of a window opening for 2 hours on the second day as shown in Figure 3.

Method 2

Initial tests on a nonlinear missile pitch rate autopilot have shown promising results. The input–output relationship between the missile's control surface and pitch rate was successfully identified and the same high-performance control was achieved as when using the fully modelled input–output relation obtained from the state space missile model. The controller design method is now being applied for building temperature control. This method should significantly reduce the difficulty of developing high-performance BEMS as well as eliminating the need for constant re-tuning of the building's control system which is both costly and time-consuming.

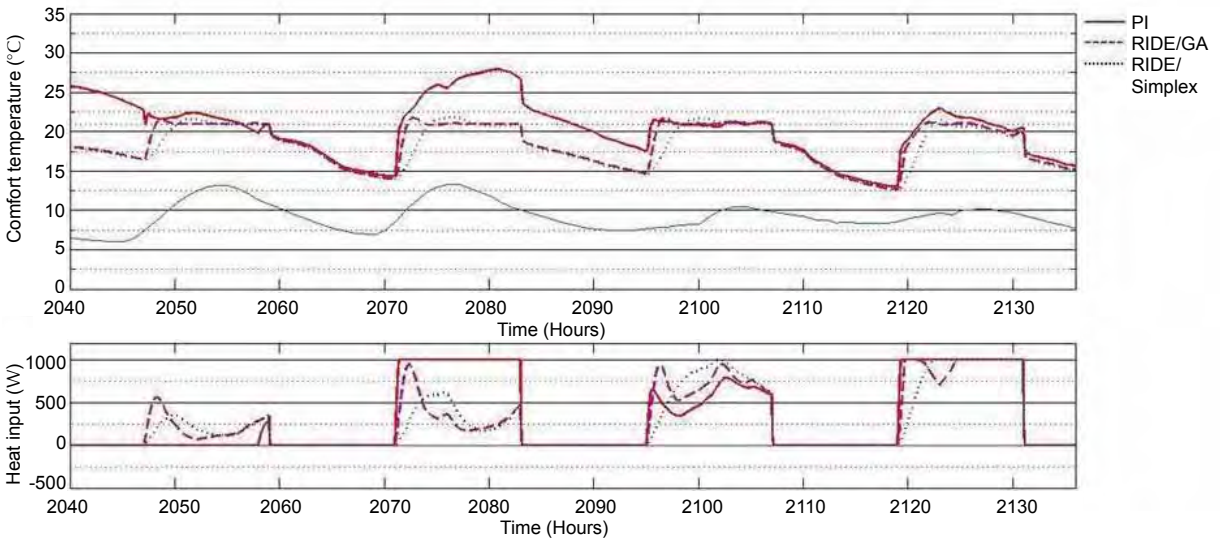

Figure 2: Comfort temperature and heat input

PI = Proportional + Integral; RIDE = robust inverse dynamic estimation; GA = genetic algorithm.

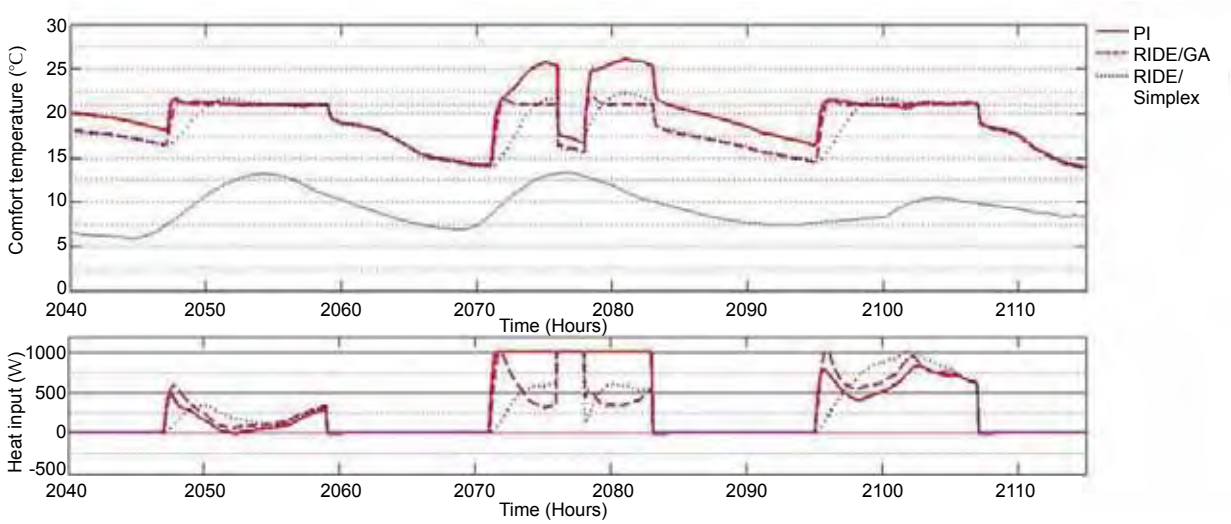

Figure 3: Comfort temperature and heat input with disturbance

PI = Proportional + Integral; RIDE = robust inverse dynamic estimation; GA = genetic algorithm.

PUBLICATIONS/RESEARCH OUTPUT

Counsell J M, Zaher O S and Brindley J. Auto-tuning for high performance autopilot design using robust inverse dynamics estimation. Proceedings of 5th International Multi-Conference on Computing in the Global Information Technology (ICCGI 2010), Valencia, 20–25 September 2010. pp 10–17.

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FIRE AND SECURITY

IS BIOMETRIC SECURITY RELIABLE?

Jeremy Fraser-Mitchell

Fire Safety Engineering Group, BRE Global

SUMMARY

This project involved a scoping study in which a literature review was carried out to understand the problems experienced with biometric readers, and to examine the business opportunities for BRE Global.

The literature review covered generic features of biometric systems, specific types of biometric system available, problems encountered by biometric systems, Codes and Standards, and testing and certification schemes, and also identified organisations involved with biometric technologies.

BACKGROUND

Recent years have seen a significant growth in biometric research resulting in the development of innovative sensors, robust and efficient algorithms for feature extraction and matching, enhanced test methodologies, and novel applications.

A biometric is a physical or biological feature or attribute that can be measured. Examples of biometric features include fingerprints, the pattern of veins, retina or iris, and the shape of the hand or the face (Figure 1). Examples of behavioural biometrics are voice patterns, signature and gait.

Biometric identifiers are potentially more reliable for person recognition than traditional token-based methods (eg keys or ID cards) or knowledge-based methods (eg password or PIN). However, biometric identification systems are subject to errors and circumvention and thus are not perfect. It is important for users of biometric identification systems to understand this.

This project has been conceived following the bad press associated with the high rates of false rejection for biometric readers used in some high-profile security applications. To date, there has been little actual field data made publicly available to enable the reasons for the apparent high rejection rates to be independently evaluated.

The first stage of the project (the subject of this summary) had the following specific objectives:

- to conduct a literature review to understand the problems experienced with biometric readers
- to define the business opportunities for BRE Global
- to identify potential sponsors/partners/stakeholders for the second stage.

RESEARCH PROGRAMME

The salient points of the literature review covered the following topics:

- generic features of biometric systems
- types of biometric system available

Figure 1: Examples of biometric features

- problems encountered by biometric systems (generic or specific to particular biometrics)
- codes and standards
- testing and certification schemes
- organisations involved with biometric technologies.

All biometric systems have a number of generic features. First, there is the sensor technology that is used to image or capture the biometric trait. These data are stored, either in a central database or a distributed

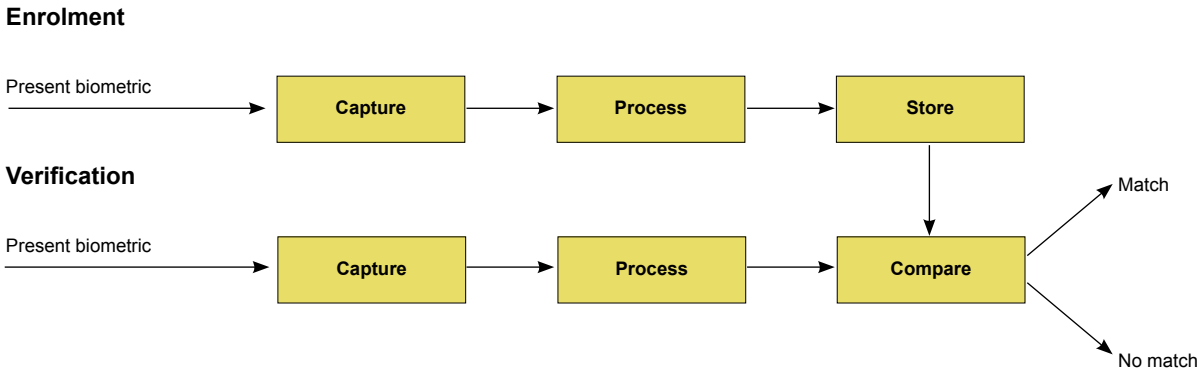

Figure 2: Process of enrolment and authentication

system (eg smart cards carried by individuals). Once a person has been 'enrolled' by the system, subsequent use requires comparison of the scanned biometric with the stored data. A statistical test is needed to assess whether or not the biometric matches the stored data, since measurement errors, for example, ensure that the biometric will not be captured identically each time.

A diagram illustrating the process of Enrolment and Authentication is shown in Figure 2.

As a consequence of the statistical nature of the acquisition and matching stages, biometric systems are never 100% accurate. Various types of errors may arise; the magnitudes of these vary from one biometric technology to another and depend on the threshold used to determine a 'match'. This threshold is set by the operators depending on the application.

Some performance measures are based on error rates, defined in BS ISO 19795-1[1], including:

- *Failure-to-enrol rate (FTE):* proportion of the population for whom the system fails to complete the enrolment process
- *Failure-to-acquire rate (FTA):* proportion of verification or identification attempts for which the system fails to capture or locate an image or signal of sufficient quality
- *False non-match rate (FNMR):* proportion of genuine attempt samples falsely declared not to match the template of the same characteristic from the same user supplying the sample
- *False match rate (FMR):* proportion of zero-effort impostor attempt samples falsely declared to match the compared non-self template
- *False reject rate (FRR)* - proportion of verification transactions with truthful claims of identity that are incorrectly denied
- *False accept rate (FAR)* - proportion of verification transactions with wrongful claims of identity that are incorrectly confirmed.

BS ISO/IEC 19795:2006

BS ISO/IEC 19795:2006 'Information technology — Biometric performance testing and reporting'[1] is likely to be central to any testing and certification of biometric systems. The first four parts have been published and are summarised below. Two other parts are in preparation.

Part 1

Part 1 establishes general principles for empirical performance testing and specifies performance metrics for biometric systems. These will generally be applicable to all biometric systems and devices.

Biometric technical performance testing can be of three types:

- technology evaluation
- scenario evaluation or
- operational evaluation.

Technology evaluation

A technology evaluation tests the matching or extraction algorithm of the biometric system. A corpus of recorded biometric samples may be used for this, rather than using live subjects. It may also test other components such as different sensor types. A technology evaluation can determine most of the error rates to be expected (in ideal conditions).

Scenario evaluation

A scenario evaluation tests the system as a whole. It determines critical performance factors and measures *simulated* operational performance. While testing the operational performance is the ultimate goal, scenario testing is more controllable, eg using a known test crew population, so that error rates can be measured. With a large enough test crew, in order to reduce the statistical uncertainty in the results, scenario evaluation can also estimate error rates such as FMR, FNMR, FTA, FTE, FAR, FRR, under more realistic conditions. In addition, scenario testing can predict the end-to-end throughput rate, ie how quickly the system acquires the biometric, scans its database and makes a decision.

Operational evaluation

An operational evaluation tests the system as a whole and measures *actual* operational performance.

Part 2

Part 2 addresses technology and scenario evaluation in more detail. The majority of biometric tests are of one of these two generic evaluation types.

Part 3

Part 3 provides guidelines for developing specific test procedures for different biometric modalities. These guidelines are intended to ensure that not only specialists of biometrics but also non-specialists can carry out reasonably accurate testing. Six modalities are explicitly considered: fingerprint, face, iris, hand vein, voice, and signature recognition.

Part 4

Part 4 prescribes methods for technology and scenario evaluations of multi-supplier biometric systems that use biometric data conforming to biometric data interchange format standards.

It might be thought that in many commercial security applications (eg access control in an office), the system would be provided by a single supplier and thus interoperability would not be a consideration. However, interoperability can avoid the problem of 'vendor lock-in'.

PROJECT OUTCOMES/CONCLUSIONS

The literature review was completed, a draft proposal for further stages in this project was produced and possible partners for the further stages were identified.

RESEARCH OUTPUT

A BRE *Information Paper* has been drafted to give an overview of biometric systems and the Standards being developed. It is expected to be published by IHS BRE Press in 2012/13.

REFERENCE

1 BSI. Information technology – Biometric performance testing and reporting. BS ISO/IEC 19795. London, BSI, Various dates.

Part 1: Principles and framework. 2006.
Part 2: Testing methodologies for technology and scenario evaluation. 2006.
Part 3: Modality-specific testing. 2006.
Part 4: Interoperability performance testing. 2006.
Part 5: Performance of biometric access control systems (Not yet published).
Part 6: Testing methodologies for operational evaluation (Not yet published).

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BRE CENTRE OF EXCELLENCE IN FIRE SAFETY ENGINEERING, UNIVERSITY OF EDINBURGH

José Torero

BRE Trust/RAEng Professor of Fire Safety Engineering

Through 2011, the Centre has embarked on a number of new initiatives that are aimed at broadening the social and technical impact of fire research. Some highlights are presented here but a more comprehensive overview is available at www.eng.ed.ac.uk/fire.

The Centre saw the launch of the IT-SAFE (Integrating Technical and Social Aspects of Fire Safety Engineering and Expertise) project in November under the leadership of Professor Robin Williams (Sociology) and Dr Luke Bisby (Fire Safety Engineering). This research will be geared towards improving fire safety and the quality of the built environment through improved interaction and integration of social scientific and engineering research. The project will bring a new academic staff member to the Centre sponsored by The Ove Arup Foundation, The Royal Academy of Engineering and the University of Edinburgh. More information about the project can be found at the dedicated project website: http://www.stis.ed.ac.uk/research_projects/it-safe.

The Centre has consistently focused on addressing fire safety issues in complex infrastructure, among which, tall buildings represent an example of extreme optimisation of structural, safety and sustainability concepts. A proposal for >£1 million submitted to the Engineering and Physical Sciences Research Council (EPSRC) was approved to start in January 2012. The project entitled 'Real fires for the safe design of tall buildings' will involve an integrated modelling and large-scale experimental study. Experiments will be carried out in the BRE Burn Hall and then finally in a real building following the success of the Dalmarnock Fire Tests. The project aims to provide fire loading conditions relevant to the large open spaces typical of tall buildings so that the essential parts of the fire safety strategy can be quantitatively assessed and integrated to the other design objectives. It has some 20 partners internationally including architects, consultants, standards agencies, fire services and insurance companies.

A new project called the Toronto Toilet has begun in collaboration with the University of Toronto and the University of Western Ontario. The project, sponsored by the Bill and Melinda Gates Foundation hopes to reinvent the toilet so that waste can be treated in-situ in areas of the world where sewage systems do not exist. The Centre is utilising fire research to sterilise waste through sub-surface smouldering combustion in a robust and low-cost manner consistent with the needs of underdeveloped countries.

Figure 1: Members of the Fire Group undertaking fire fighter training at the Scottish Fire Services College, Gullane in December 2011

This year, the Centre graduated five PhD students covering a broad range of subjects from forest fire studies to structural behaviour in fire. Among the graduating students is the BRE Trust sponsored Dr Angus Law. Dr Law's thesis, *The assessment and response of concrete structures subject to fire*, received the Best PhD Thesis Award in the Europe/Africa region at the International Symposium for Fire Safety Science conference in Maryland in June. A paper based on his thesis received the 2011 Lloyd's Science of Risk Prize in the Biological/ Technological Category. Dr Sung-Han Koo, a former PhD student now working with BRE, received the best runner-up prize in the same category. Dr Thomas French has completed his viva and is awaiting graduation for his thesis titled, *Evolutionary optimisation of network flow plans for emergency movement in the built environment*. Adam Ervine has completed his thesis, *Damaged reinforced concrete structures in fire,* and is awaiting his viva examination in early 2012. The research conducted by Angus, Adam and Thomas is summarised in the following pages.

In 2011, the Centre gained a further four PhD students, two of whom are sponsored by BRE Trust:

- Ryan Hilditch will investigate smoke management in the modern built environment where complex flow

control systems are becoming an important means for energy management
- Martyn McLaggan will work towards the development of an integrated methodology to assess thermal and fire performance of phase change materials as a novel means to manage energy consumption in buildings.

PhD student Christian Maluk was awarded Best Student Poster Award for the second time at the International Symposium for Fire Safety Science.

Following its inaugural year in 2010, the International Master of Science in Fire Safety Engineering (IMFSE) has received the inaugural FireForum Award 2011 in the Social Value category. The IMFSE program is an EU Erasmus Mundus degree coordinated by Ghent University (Professor Bart Merci) in association with Lund University (Professor Robert Jönsson) and the BRE Centre at the University of Edinburgh (Professor José Torero).

The Centre hosted the second annual BRE University Centres of Excellence Student Conference in July 2011. The event was well attended and the quality of the presentations given and creations assembled for the design and build competition were extremely impressive.

The Centre also hosted the 2011 Lloyd's Register Educational Trust (LRET)/University of Edinburgh Global Technical Leadership Seminar in Fire Safety Engineering. This represented the first in a series of three annual week-long intensive seminars ('think tanks') focused on areas related to fire safety engineering. The seminar had the theme of 'Education for the future of fire safety engineering', and was held in Scotland 30 May–3 June 2011. Participants were selected from key players in defining the present and future of fire safety engineering as a professional/academic discipline. BRE was represented by David Crowder. The next event is scheduled for June 2012 and will focus on how structural engineering is required to evolve to meet current fire safety needs.

The Centre continued with its annual one-day symposium FireSEAT, which in 2011 was entitled 'The science of suppression' and featured the Thomas Lecture given by Dr Ron Alpert (formerly of FM Global) and a range of excellent presentations from world-leading experts in the field.

For further information on any of these projects or the articles that follow, contact Professor José Torero,
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THE ASSESSMENT AND RESPONSE OF CONCRETE STRUCTURES SUBJECT TO FIRE

Angus Law

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SUMMARY

Over the past 20–30 years, much of the research in structural fire engineering has been on the behaviour of steel; the performance of concrete has been relatively neglected. The work in this project analyses the behaviour of concrete structures to develop new techniques for structural modelling and design. Specifically, this project aimed to:

- understand how concrete material behaviour and the way it is modelled can affect structural response
- develop a method for assessing structural capacity during and after a fire
- develop a methodology for assessing whole building behaviour aspects during and after a fire
- understand whether, and how, different design fires can affect a concrete structure.

BACKGROUND

Over the past 20–30 years, the field of structural fire design has shifted from relying on single element fire resistance testing to the consideration of the effects of full-frame behaviour. The change has been driven by the desire to build more advanced structures and reduce costs. It has been facilitated in part by structural testing, and in part by development of complex modelling techniques.

RESEARCH PROGRAMME

Sectional analysis

Sectional analysis allows designers to determine quickly the amount of reinforcement required to resist certain moments and axial forces. In ambient conditions, they are simple to create because a maximum allowable strain is defined to prevent crushing. When high temperatures are introduced, the crushing strain of the concrete increases. Consequently, interaction diagrams become much more difficult to define and a large number of trial points are required.

A new technique was created which allows the huge number of calculations usually required to generate an interaction surface to be circumvented. It used the properties of the determinant of the tangent stiffness matrix to find the ultimate capacity of the section. The new method was applied to find biaxial interaction diagrams for concrete sections subject to various fires (Figure 1). It was found that the 500 °C isotherm method was unconservative. The origins of the unconservatism in the isotherm method were traced to the assumption of ambient temperature in active concrete and the inaccuracies inherent in the stress block method.

Load-induced thermal strain

Transient strain, or load-induced thermal strain (LITS) occurs in concrete as it is heated under some degree of pre-stress. It is well characterized at a material level, but

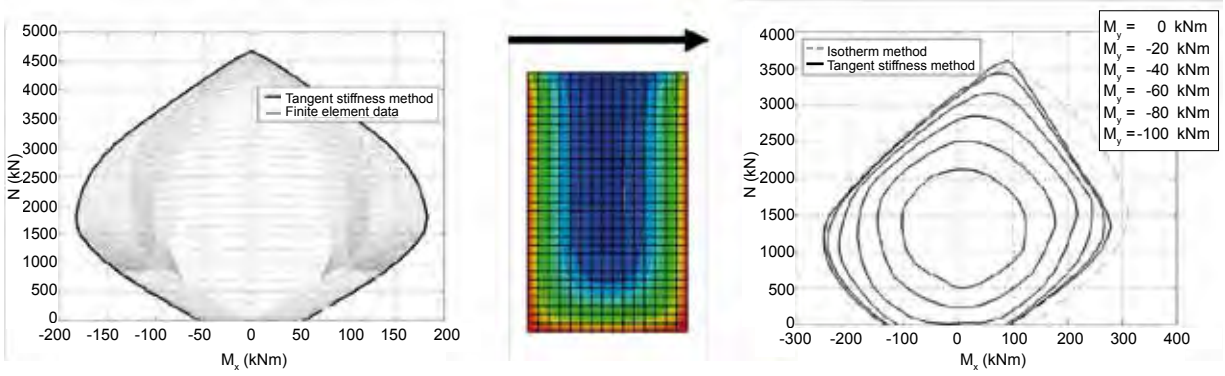

Figure 1: Sectional analysis before and during exposure to fire

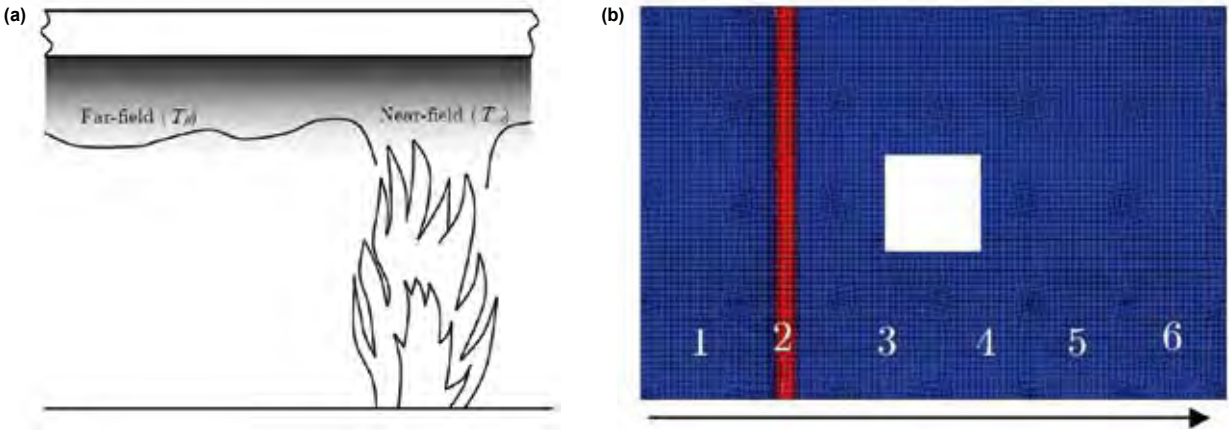

Figure 2: (a) A fire in a large enclosed area, (b) a fire travelling across a floor plate

little understood in terms of its structural impact. Current methods for modelling LITS were reviewed, and a new way of including LITS in finite-element-models was introduced.

Travelling fires

A series of experimental and accidental case studies have shown that fires do not burn in a uniform fashion. In small compartments, temperature variations can be extreme and, in large areas, fires can move around the floorplate gradually. To account for this, a design methodology was developed to represent the temperatures to which a structure might be exposed by a travelling fire as it moved across the floorplate (Figure 2). The methodology, developed by Stern-Gottfried et al[1], split the floorplate into:

- a hot area near to the fire (the near-field)
- a cooler area further away from the fire (the far-field).

The effect of different sizes and shapes of travelling fire were analysed with reference to a generic concrete structure. The response of the structure was measured using accepted measures of structural performance such as defection, rebar temperature and rebar strain.

Whole frame analysis

The events at Broadgate and Cardington highlighted the importance of whole frame behaviour when a building is subjected to fire. However, despite this understanding, the measures that are often used to characterise structural failure have remained relatively basic, and often arbitrary. A new approach for characterising a structure's response to a fire was created to provide a more comprehensive assessment of behaviour. A finite-element model of a generic concrete structure was subjected to a series of fires and the changes in the loading induced in members were calculated. The modified member loadings were combined with estimations of bending, axial and shear capacity to allow utilisation factors (load ratios) to be calculated for each section. This allowed the loading ratios for every part of the structure to be automatically calculated.

PROJECT OUTCOME/CONCLUSIONS

Sectional analysis

It was found that modification of the various safety factors in the stress block method did not result in a conservative sectional analysis and that explicit consideration of the changing strain-at-peak-stress is required for representative interaction diagrams.

Load-induced thermal strain

It was found that current design methods underestimate the development of plastic strain (Figure 2), and that these effects become critical on cooling.

Travelling fires

It was universally found that fires that engulfed 10–25% of the floorplate at any one time induced the most extreme structural response. It was also found that in many cases, the travelling fires induced a more extreme structural response than conventional codified fires.

Whole frame analysis

The methodology enables standardized reports to be prepared for the whole structure (Figure 3). Thus, it is possible to compare the effects of different fires in a quantitative manner. The overall trends due to a number of fires can also be analysed, and design modifications can be made based on the results. Thus, it is possible to achieve a relatively uniform degree of safety across the structure.

For more detailed information on this project, an electronic copy of the final thesis can be found at www.era.lib.ed.ac.uk/handle/1842/4574.

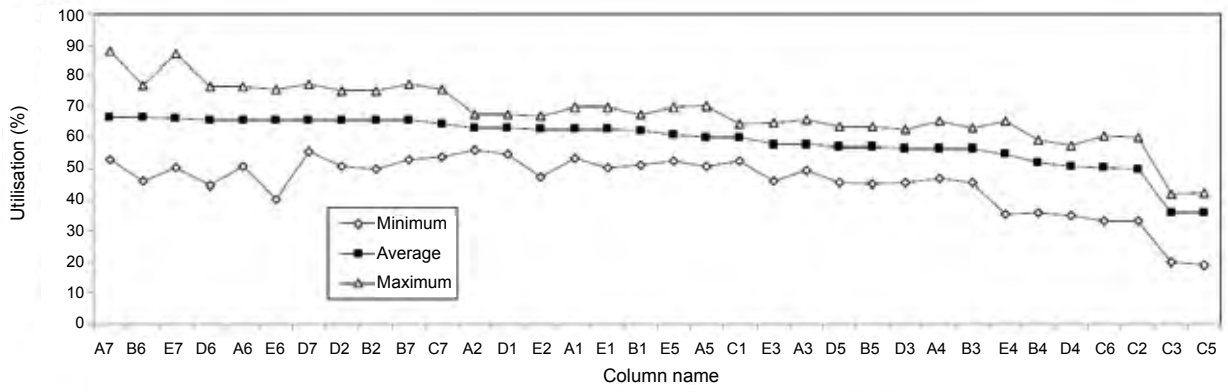

Figure 3: Percentage assessment of each column in the structure

RESEARCH OUTPUT

Law A, Gillie M, Stern-Gottfried J and Rein G. The influence of travelling fires on a concrete frame. Engineering Structures, 2011, 33, 1635–1642.

Law A and Gillie M. Interaction diagrams for ambient and heated concrete sections. Engineering Structures, 2010, 32 (6), 1641–1649.

Stern-Gottfried J, Law A, Rein G, Gillie M and Torero JL. A performance based methodology using travelling fires for structural analysis. Paper presented at 8th International Conference on Performance-Based Codes and Fire Safety Design Methods, Lund University, Sweden, 16–18 June 2010.

REFERENCE

1 Stern-Gottfried J, Law A, Rein G, Gillie M and Torero JL. A performance based methodology using travelling fires for structural analysis. Paper presented at 8th International Conference on Performance-Based Codes and Fire Safety Design Methods, Lund University, Sweden, 16–18 June 2010.

DAMAGED REINFORCED CONCRETE STRUCTURES IN FIRE

Adam Ervine

BRE Centre of Excellence in Fire Safety Engineering, University of Edinburgh

SUMMARY

The research studied how damage manifested itself within reinforced concrete subjected to extreme mechanical loads and how this affected the thermal resistance of members and structures.

First, an experiment was conducted to look at how the thermal profile was affected by tensile cracks. Secondly, numerical studies were carried out to determine what effect the loss of concrete cover had on the thermo-mechanical behaviour and this was the applied experimentally to a full-scale reinforced concrete structure. Finally, the use of embedded fibres (synthetic and steel) within the concrete were experimentally investigated with the aim of retaining the concrete cover and hence the thermal resistance throughout an extreme mechanical event.

BACKGROUND

Much research has been carried out into reinforced concrete and its constitutive parts under extreme mechanical loading conditions[1–6]. A lot of work has also been carried out into the thermal properties of steel and concrete from ambient to high temperatures and the thermal resistance of reinforced concrete members and structures including spalling[7–11].

Structural loads such as earthquakes, impacts and blasts can cause widespread damage to structural and non-structural components. Economic considerations dictate that for designing reinforced concrete structures under these extreme loads there is an allowable capacity for plastic deformations to occur. Due to the nature of reinforced concrete, these allowable plastic deformations can bring about localised effects such as tensile cracking or compressive crushing and removal of the concrete cover. These localised effects can be devastating in terms of the fire resistance of the structure as the concrete cover may have been become compromised. The thermal insulation properties of the concrete cover may have become reduced or the cover may be removed completely leading to direct heating of the reinforcement. Here lies the fundamental and major inconsistency between the design methods for fire and other extreme events that cause mechanical damage.

RESEARCH PROGRAMME

The effect of tensile cracking on the thermal propagation through such cracks was experimentally investigated. Reinforced concrete members as shown in Figure 1 were mechanically loaded to produce a pre-determined level of cracking. These members were then subjected to a constant thermal load onto the cracked surface and the thermal profile throughout the member was measured using embedded thermocouples. Figure 2 shows the thermal profile comparison between an undamaged member and a member that has undergone major cracking (ie crack widths of the order of 101 mm). From Figure 2, it can be seen that tensile cracking produces no significant effect on the thermal propagation through these cracks when compared with an intact specimen.

The loss of or partial loss of the concrete cover was numerically investigated to determine its effect on the thermo-mechanical behaviour of a reinforced concrete structure (simple portal frame). This was first carried out with the user manually stating where the cover had been removed, applying a thermal load to the internal surfaces. This thermal load was ramped to maximum within 300 s and kept constant for the remainder of an hour. The thermal load was then returned to ambient within 300 s and kept constant for the remainder of an hour. The thermo-mechanical behaviours were recorded and compared.

This method is extremely labour-intensive, therefore a subroutine was written to allow the loss of cover to be automatically determined throughout (but not fixed to) the mechanical and thermal steps. Figure 3 illustrates how the loss of cover affects the thermal propagation through a section. This method of numerical modelling was also applied to a full-scale reinforced concrete structure that was experimentally tested in India with great effect. The loss of concrete cover was shown to have a profound effect on the thermo-mechanical behaviour of the structures. Therefore, it is necessary to provide a method for retaining the concrete cover and hence retaining the thermal resistance of the structure and members.

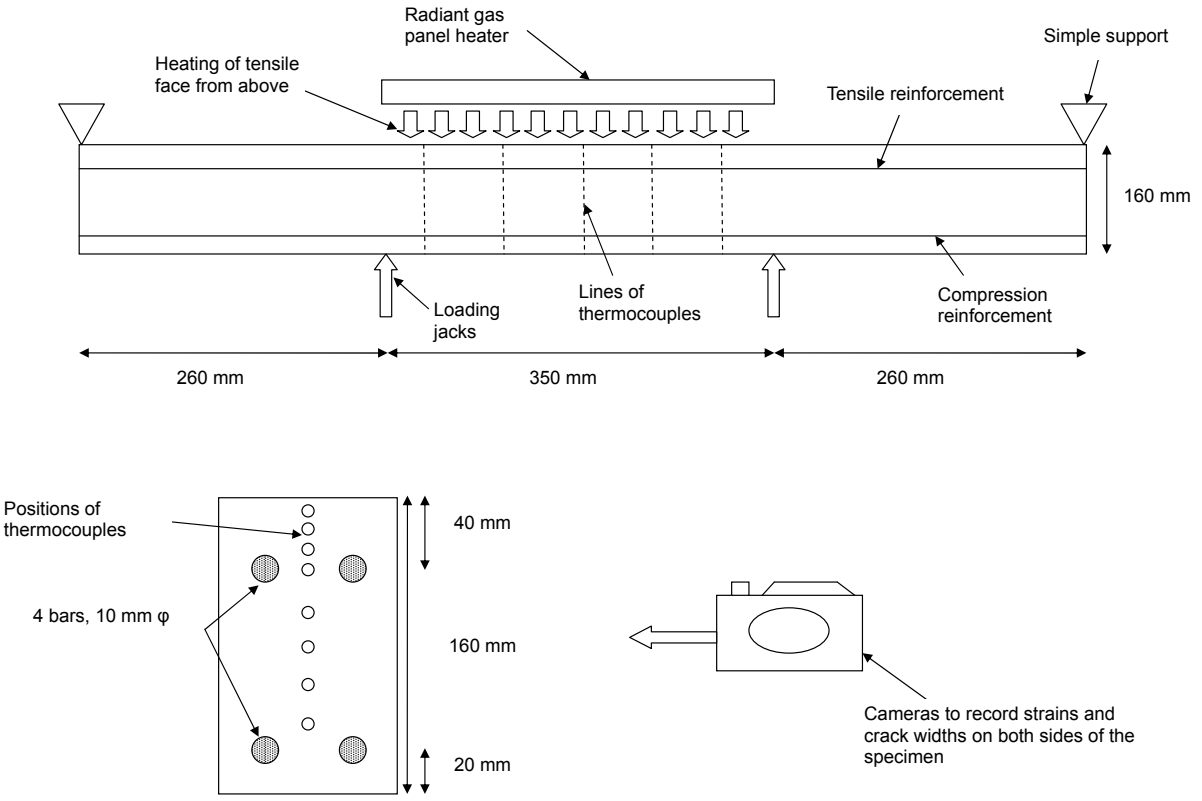

Figure 1: Experimental apparatus set-up for the investigation into the thermal propagation through tensile cracks in reinforced concrete. A side-view of a beam, a typical section and general locations of the thermocouples are shown

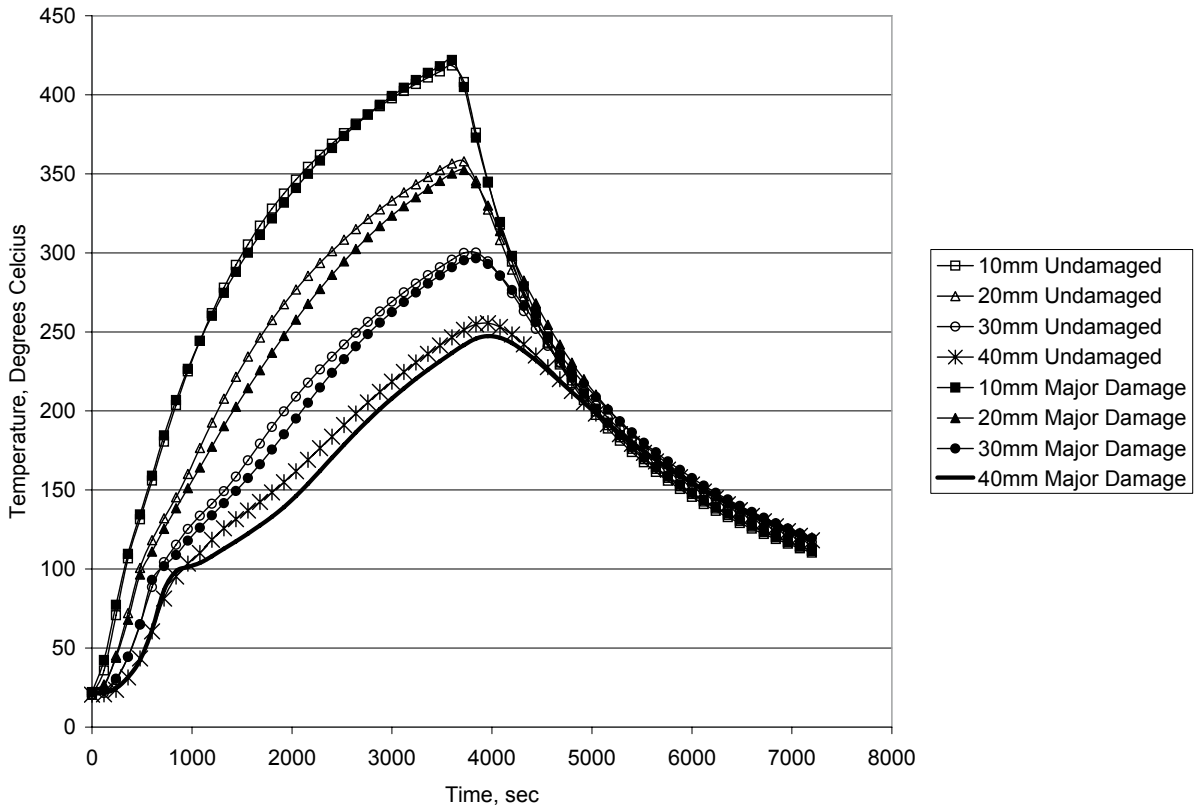

Figure 2: Comparison of temperature profile for undamaged and major damaged sections for the investigation into the thermal propagation through tensile cracks in reinforced concrete

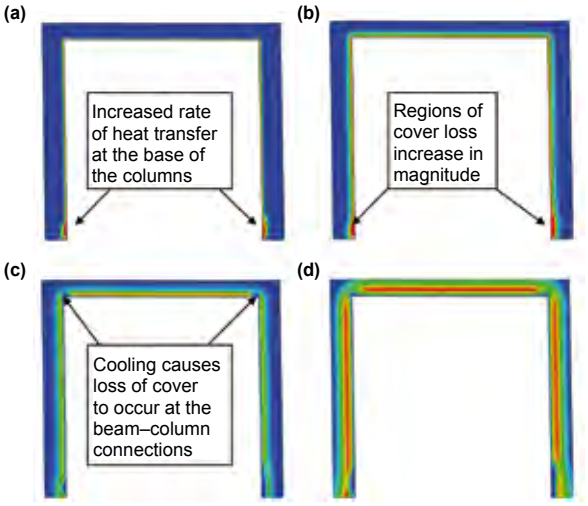

Figure 3: Thermal profiles of the frame where cover loss is simulated throughout the mechanical and thermal phases: (a) 300 s, (b) 3600 s, (c) 3900 s, (d) 7200 s. The heat transfer is not uniform and continuously changes throughout the thermal phase

Embedded fibres (both synthetic and steel) were used to provide the mechanism for retaining the presence of the concrete cover. Beam members similar to those shown in Figure 1 were loaded to a pre-determined mid-span deflection (or curvature) to cause crushing of the compressive surface. Figure 4a illustrates how loss of the concrete cover occurs within a non-fibrous beam due to crushing, whereas Figure 4b shows almost no loss of concrete cover even though both beams were loaded to the same crushing curvature.

PROJECT OUTCOME/CONCLUSIONS

It has been shown through experimentation that tensile cracking does not significantly affect the thermal propagation and therefore does not significantly affect the thermal resistance. However, on the other hand, it has been shown that the loss of the concrete cover has a profound effect on both the thermal propagation and thermo-mechanical performance of a reinforced concrete frame.

A significant finding of this research is that the use of uniformly distributed embedded fibres into the concrete

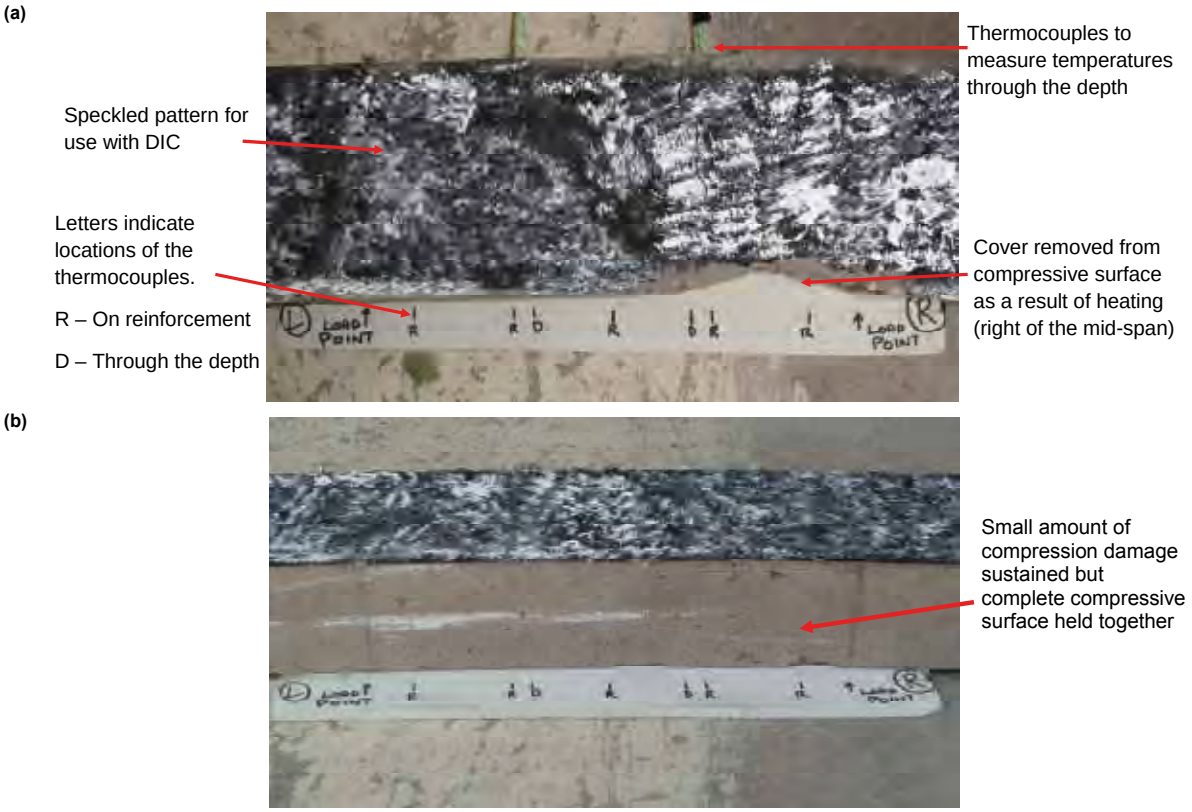

Figure 4: (a) Loss of cover during thermal loading in a non-fibrous beam, (b) beam containing micro-synthetic fibres after mechanical and thermal loading. A small amount of compression damage is shown but no loss of concrete cover is sustained

mix clearly enhances the overall mechanical, thermal and thermo-mechanical behaviour of reinforced concrete subjected to extreme loading conditions (see Figure 4b).

RESEARCH OUTPUT

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EVOLUTIONARY OPTIMISATION OF NETWORK FLOW PLANS FOR EMERGENCY MOVEMENT IN THE BUILT ENVIRONMENT

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SUMMARY

An emergency movement problem, the maximal safest escape (MSE) problem, is formulated in terms that model the uncertain and transient environmental conditions of emergency evacuation in the built environment, as a flow problem in time-dependent networks with time-varying and stochastic edge travel times and capacities (STV networks). The objective of the MSE problem is to find the routing plans with the highest likelihood of successfully evacuating occupants from initial locations to points of safety. A solution approach based on a state-of-the-art framework for solving stochastic optimisation problems is proposed and empirically evaluated against competing methods.

BACKGROUND

Planning for emergency evacuation and, more generally, for emergency movement involving both evacuation (egress) of occupants and ingress of first responders, presents important and challenging problems. A number of the current issues that arise during emergency incidents are due to the uncertainty and transiency of environmental conditions. In general, movement plans are formulated at building design time, and those involved, such as building occupants and emergency responders, are left to adapt routing plans to actual events as they unfold. In the context of future emergency response systems, it has been proposed to plan dynamically and route individuals during an emergency event, re-planning to take account of changes in the environment.

RESEARCH PROGRAMME

In this project, an emergency movement problem, the maximal safest escape (MSE) problem, was formulated in terms that model the uncertain and transient environmental conditions as a flow problem in time-dependent networks with time-varying and stochastic edge travel-times and capacities (STV networks). The objective of the MSE problem is to find flow patterns with the *a priori* maximal probability of successfully conveying all supply from the source to the sink in some given STV network. The MSE and its deterministic counterpart were proved to be non-deterministic polynomial-time hard, meaning that efficient, exact solution methods are unlikely to be proposed. Furthermore, due to inherent complexity in evaluating the exact quality of candidate solutions, a simulation approximation method was presented based on well-known Monte-Carlo sampling methods.

Given the complexity of the problem, and using the approximation method for evaluating solutions, it was proposed to tackle the MSE problem using a metaheuristic approach based on an existing framework that integrates evolutionary algorithms (EAs) with a state-of-the-art statistical ranking and selection method, the optimal computing budget allocation (OCBA). Several improvements were proposed for the framework to reduce the computational demand of the ranking method.

The approach was compared with a simple approach and conditions under which the integrated framework is more efficient were investigated. The performance of the EA was compared against upper and lower bounds on optimal solutions. An upper bound was established through the 'wait-and-see' bound, and a lower bound by a naive random search algorithm (RSA). An experimental design was presented that allows for a fair comparison between the EA and the RSA. While there is no guarantee that the EA will find optimal solutions, the work demonstrated that the EA can still find useful solutions. Useful solutions are those that are at least better than some baseline, in this case the lower bound, in terms of solution quality and computational effort. Experimentally, it was demonstrated that the EA performs significantly better than the baseline. Also, the EA finds solutions relatively close to the upper bound; however, it was difficult to establish how optimistic are the upper bounds. The main approach was also compared against an existing approach developed for solving a related problem

wrapped in an heuristic procedure in order to apply the approach to the MSE. Empirical results showed that the heuristic approach required significantly less computation time, but found solutions of significantly lower quality.

PROJECT OUTCOMES/CONCLUSIONS

This work introduces and empirically verifies the efficacy of a metaheuristic based on a framework integrating EAs with a state-of-the-art statistical ranking and selection technique, the OCBA, for a novel flow problem in STV networks. It is suggested that the lessons learned during the course of this work, along with the specific techniques developed, may be relevant for addressing other flow problems of similar complexity.

RESEARCH OUTPUT

French T, van Hemert J, Potter S, Wickler G and Tate A. An evolutionary algorithm for the safest weighted escape problem in stochastic, time-varying networks. Paper presented at VIII Metaheuristic International Conference, Hamburg, Germany, 13–16 July 2009.

SUSTAINABILITY

LOW FLOW WATER FITTINGS – WILL PEOPLE ACCEPT THEM?

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SUMMARY

Growth in water demand is becoming unsustainable. Average household demand has risen by about 55% in the past 25 years and continues to rise at 1% per year. Taps account for 34% of domestic water supplied in England and Wales.

This project concentrated on low flow taps because so little is known about how taps are used, and what matters in tap performance. The chief objection to low flow fittings is the extra time required to carry out most ordinary tasks. This is evident from:

- an experiment with the BRE low flow water fittings test rig at Insite09
- a focus group study
- a literature review.

BACKGROUND

There is increasing concern in the UK that the demand for wholesome water will soon begin to exceed supply, particularly in South East England. The challenges of global warming, climate change and population growth will exacerbate this problem which has been increasing in severity across Europe for more than 30 years. Decisive action is essential if acceptable water supplies are to be maintained.

It is now widely understood that that the total volume of water consumed by a tap is largely determined by the user[1–4]. Although low flow taps and restrictors may help to reduce water consumption, low flow rates may be a nuisance for some users. The time taken to fill a bath or a kettle will depend on the tap flow rate[5]. In a study to monitor the water use in dwellings built to the standards of the Code for Sustainable Homes (CSH) and Ecohomes[4], researchers found that in some CSH homes the bath taps are sometimes used for filling containers that would normally be filled at either a basin or sink. This happens especially in dwellings where low flow taps have been supplied for kitchen sinks and wash hand basins while the bath taps are unrestricted.

RESEARCH PROGRAMME

The research programme included:

- a literature review of public attitudes and behaviour with water use
- an experiment using a specially designed rig to test public opinion about low flow water fittings
- a focus group
- a survey of manufacturers and installers

Figure 1: Filling a 300 ml beaker at a flow rate of 1.2 litres per minute

- an examination of European and UK policy
- identification of organisations and schemes promoting water conservation in the UK
- publication of conclusions and recommendations drawn from the work in a BRE report.

Experiment using the low flow water fittings test rig

An experiment using a specially designed test rig (Figure 2) was carried out with a total of 339 visitors to

Figure 2: Specially designed test rig used to assess public opinion about low flow water fittings at BRE's Insight09 event

the BRE exhibition, Insite09, held 1–4 June 2009 at the Watford site. Participants were invited to do one of three tasks at three flow rates under the supervision of the experimenter. The three test flow rates were chosen to reflect the extremely low flows being encouraged at the time to meet the highest standards under the CSH.

The tasks were to:

- wash their hands with liquid soap and cold water
- fill a 300 ml beaker
- fill a 1.7 litre kettle.

The flow rates were:

- low (1.2 litres per minute)
- medium (3 litres per minute)
- high (4.2 litres per minute).

Each person carrying out a test was invited to say whether the flow rate was acceptable or not acceptable for whichever of the activities he/she undertook. A summary of the results is given in Table 1.

The acceptability of the flow rate was strongly task-dependent. There was little effect on satisfaction due to the flow presentation (plain, spray or aerated), although this response modified slightly, especially at the high flow rate. There was also not much effect due to the gender and age of participants. The low flow rate was least preferred for all three tasks.

Table 1: **Summary of acceptability responses to tasks and flow rates**

Task (all presentations, ages and both genders)	Acceptability (%)		
	High 4.2 l/min	Medium 3 l/min	Low 1.2 l/min
Kettle	85	64	24
Beaker	79	90	64
Handwashing	80	89	67

Focus group

The focus group showed that asking people for their opinions of water flow rates is meaningless unless they can experience them in the context of everyday tasks.

Survey of manufacturers and installers

The survey of manufacturers and installers suggested that householders show little interest in water saving. The features that interest them most in a tap are appearance, performance and cost. This is supported by the literature review and the results from the focus group.

CONCLUSIONS

The straightforward answer to our original question 'will people accept low flow water fittings?' is 'No'! At least, not unless a great deal of care is taken to ensure that low flow fittings do not interfere with the performance that people need and expect.

The chief objection to low flow fittings is the extra time required to carry out most ordinary tasks. This is evident from the experiment with the BRE low flow water fittings test rig, the focus group study and from the literature review, where recent work done by BRE on new homes meeting the standards for the CSH showed that people fill vessels using unrestricted bath taps where their kitchen or basin taps have an unacceptably low flow rate[4].

The lack of popular interest in water conservation is surprising given the positive attitudes people have to energy saving, and in particular, buying energy-saving white goods. The reason may be due to a deep-seated and enduring cynicism about the role of water companies in reducing leaks in the public water supply system, and the conviction that the influence of individuals is small compared with this.

PUBLICATIONS/RESEARCH OUTPUT

The results of the project will be explained in more detail in a forthcoming BRE Trust report.

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A CARBON ASSESSMENT TOOL FOR COMMERCIAL PROPERTY PORTFOLIOS

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SUMMARY

In recent years, commercial property portfolio holders have become more concerned about the carbon performance of their buildings. They want to know how their buildings are performing so that they can consider actions such as improvement or disposal. However, they lack the required technical information and are concerned about the cost of acquiring it.

The tool developed through this project makes it easier to assess the carbon performance of commercial property based on the kind of information that the target audience has ready access to. It presents the comparative performance data for multiple buildings to enable portfolio holders to judge which buildings need action.

BACKGROUND

In recent years, commercial property portfolio holders have become more concerned about the carbon performance of their buildings, because:

- energy performance certificates are now mandatory at the point of sale or let
- they want to project a socially responsible image
- carbon performance can be a significant factor to influence the value and ease of sale or letting.

However, this audience is concerned to know how their whole portfolio as well as individual buildings are performing so that they can consider future actions, including improvement or disposal. At the same time, they usually lack the appropriate technical information on their buildings and are concerned about the cost of acquiring this information through conventional means.

The aim of this project was to create a tool which makes it easier to assess the carbon performance of commercial property based on the kind of limited information that the target audience has ready access to, in order to drive decision making about their buildings.

RESEARCH PROGRAMME

The project consisted of the generation of a software tool in the form of two modules:

- Energy/carbon evaluation of each building based on the limited information available
- Integration of the information for multiple buildings into an overall graphic to comapre buildings in a portfolio so that actions can be prioritised.

Ideally, this would be carried out by undertaking an Energy Performance Certificate (EPC) analysis on each building. However, collecting data for a full EPC analysis can be onerous; the aim was to undertake an analysis without having to collect the full data set.

Energy/carbon evaluation of each building

For credibility, it was decided that the actual evaluation engine should use the simplified building energy model (SBEM)[1], which is the respected free-issue calculation engine that underlies the EPC calculation in the UK and some other European countries.

A simplified input approach was developed, which provides sufficient input to drive SBEM from a limited data set. This drew on experience with the inference procedures already set up in iSBEM[2] and fed into a new interface that generates the necessary input.

Integration of the information for multiple buildings

The second module aggregates the carbon performances of multiple buildings into a single portfolio. The graphic module, based on Excel, displays information on two axes representing the carbon asset performance and operational performance of each building. This enables users to pinpoint which buildings could benefit from:

- improvements to their fabric and plant
- better management
- both of the above.

This information can be used to prompt more detailed investigations into individual buildings.

Probabilistic weather data

As a separate exercise funded through this project, BRE monitored and helped steer the progress of an

(a)

Asset						Operation				
Fossil kWh/sqm	Systems electricity kWh/sqm	Equipment electricity kWh/sqm	Total carbon kgCO2/sqm	Carbon rating	Carbon band	Fossil kWh/sqm	Total electricity kWh/sqm	Total carbon kgCO2/sqm	Carbon rating	Carbon band
159.937	145.943	56.8491	92.6159	65	Good	170	150	109	64	Good
263.457	395.458	56.849	217.994	152	Very bad	230	240	166	98	Medium
135.907	148.828	56.8492	89.1714	61	Good	220	400	244	144	Bad
148.442	165.53	56.849	98.6516	71	Good	200	200	140	113	Poor
168.091	59.8643	56.8491	57.8723	41	Very good	200	350	215	173	Very bad
0	217.117	56.8489	91.6233	62	Good	0	300	150	31	Very good
						0	0	0	0	
						0	0	0	0	
						0	0	0	0	
						0	0	0	0	

(b)

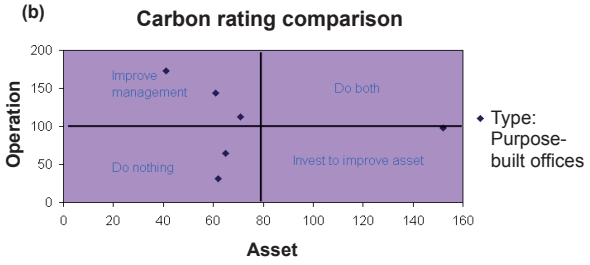

Figure 1(a), (b): Energy and carbon information about the asset and operational performance of each building

Engineering and Physical Sciences Research Council (EPSRC)-funded project at the University of Exeter called Prometheus. This aimed to define a methodology for the creation of probabilistic climate and weather data for use in energy modelling for future reference years. BRE Trust provided some funding to enable BRE to contribute advice on the data requirements for regulatory and building certification purposes, and to enable the early acquisition of the probabilistic weather data. This task was carried out by keeping in touch with the project and providing input as opportunities arose.

PROJECT OUTCOMES/CONCLUSIONS

The simplified procedure works by providing the full data set required to drive SBEM, based on a number of assumptions and simplifications. The result is not an auditable EPC but many of the variables that have a significant impact on the calculation are entered. So, the result is specific enough to the building to enable it to be used for comparing buildings within the portfolio tool.

The data required by SBEM that would normally have to be generated by an EPC assessor from examination of the building are instead inferred from a number of basic questions about the building, such as:

- what is the building area?
- how many storeys does it have?
- what is the generic shape of the building (eg is it narrow or deep plan, or square)?
- what building type is it? (eg office, hotel, school, etc).

The portfolio assessment tool consists of an Excel spreadsheet into which the results of the simplified individual building assessments are imported. The user is invited to add further information about each building, such as type and duration of tenure, type of occupant.

Where it is available, information on the operational performance of each building is added to the table (Figure 1a). This can be the information collected to enable a Display Energy Certificate (DEC) to be generated, or it can be obtained from utility records where these are paid by the landlord.

The user can view the carbon rating comparison of the resulting part (or whole) portfolio. Figure 1b shows a typical output, in this case for a small portfolio of purpose-built office buildings, and a focus on particular priority buildings.

Market testing of the tool has indicated that it fulfils its purpose at both the individual building and portfolio levels, but that further improvements to its functionality are needed before it reaches its full potential.

REFERENCES

1 BRE. SBEM. For more information, visit www.bre.co.uk/page.jsp?id=706

2 BRE. iSBEM. Available to download at www.ncm.bre.co.uk/

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LONG SERVICE LIFE CONCRETE STRUCTURES FOR AGGRESSIVE ENVIRONMENTS: Minimising sustainability impacts and whole life costs

Keith Quillin

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SUMMARY

This project has examined service life design and assessment options to meet the potentially conflicting requirements of functional performance, long-term durability, sustainability and whole life cost/maintenance associated with concrete structures.

It has considered the implications of emerging technologies.

- *Wireless sensor/data capture and data handling.* These could be used to enable remote data capture in support of asset management.
- *Low CO_2 binders that may be introduced into mainstream construction as a direct replacement for Portland cements*. These materials will have lower embodied CO_2, but there is a need to demonstrate suitable performance and whole life sustainability if they are to be used.

BACKGROUND

New energy and transport infrastructures worldwide will involve huge investment and require the creation of a new generation of long-life assets. These could include new nuclear plants, barrages for electricity generation and storm surge protection, offshore wind farms, bridges, etc. They could be in aggressive environments and be subject to demanding performance requirements (Figure 1). They will require a diverse range of concrete structures which will involve the use of large volumes of different types of concretes.

It will be important to get an appropriate balance between potentially conflicting requirements associated with:

- functional performance
- adequate durability
- sustainability
- whole-life cost
- effective through-life management of these assets.

In assessing these issues, it is necessary to take into account new and evolving technologies regarding concrete as a material and ways in which its condition and performance can be assessed. To date, concrete has been made mainly using Portland cement (PC) as the binder. Concrete made using PC has a significant amount of embodied CO_2 as the manufacture of the cement involves sizeable CO_2 emissions. Low CO_2 alternatives to PC are being developed. Their use in concrete as an alternative to PC could reduce embodied CO_2 substantially, although service life (particularly fitness for purpose throughout the life of the structure) needs to be demonstrated.

Figure 1: Concrete viaduct supporting the M25 motorway at King's Langley, Hertfordshire

There have also been considerable technical changes associated with the use of concrete as a structural

material, such as the evolution of design concepts and allied advances in construction procedures, reinforcement and prestressing systems. New wireless sensors and data capture/management systems are also emerging. These could provide opportunities for improved asset monitoring and management across a range of sectors.

RESEARCH PROGRAMME

The research programme involved the following steps:

1 A review of user requirements for log life concrete infrastructure in severe environments, current practice, and recent developments in techniques and approaches to designing structures for long-service lives and to predict performance in service.
2 The impact of new and emerging technologies particularly:
   - new low CO_2 concrete binders that may replace Portland cement in future; in particular approaches to addressing standards-related barriers
   - information and communications technology (ICT)-enabled devices that allow in-service data capture, storage and analysis to provide information to improve asset management.

PROJECT OUTCOMES/CONCLUSIONS

The project has reviewed:

- the state-of-the-art for concrete service life design and prediction
- emerging technologies for monitoring concrete structures in the context of service life and asset management.

Overall, the work has provided an overview of ways in which new technologies could be brought together in future to create sustainable, fit-for-purpose concrete infrastructure.

A number of low CO_2 cements are being developed. As an independent organisation with a strong track record in this area, BRE is well placed to support manufacturers in addressing barriers to market, particularly in the context of concrete standards and the test-based data needed to support them. The project has allowed us to review the steps likely to be involved in moving these products through the standardisation process.

PUBLICATION/RESEARCH OUTPUTS

This work has led to the preparation of draft BRE *Information Papers* which will be published by IHS BRE Press in 2012/13:

Dunster A, Nixon P and Quillin K. Deterioration processes affecting concrete. BRE Information Paper (in preparation).

Nolan E and Quillin K. Service life of concrete structures. BRE Information Paper (in preparation).

Bassi R, Dunster A, Matthews S, Nolan E and Quillin K. Service life of concrete structures: exploring potential benefits of emerging data capture and management technology. BRE Information Paper (in preparation).

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BRE CENTRE OF EXCELLENCE IN SUSTAINABLE DESIGN OF THE BUILT ENVIRONMENT, CARDIFF UNIVERSITY

Christopher Tweed

Professor, Sustainable Design of the Built Environment

The main research focus for the BRE Centre for Sustainable Design of the Built Environment is in improving interactions between people and the built environment. Research carried out in the Centre recognises the need for a holistic approach to sustainable design, embracing social and economic aspects of sustainability as well as environmental concerns. If we are to reduce carbon dioxide emissions and our reliance on energy consumption then it will require imagination to develop solutions to persuade people to abandon the 'business as usual' attitude.

The Centre continues to develop its research portfolio on the evaluation of building performance. Although this entails the physical measurement of the thermal and visual environments created in buildings, the Centre's interest is primarily focused on what these conditions mean for the occupants. Three projects have significant elements of post-occupancy evaluation.

CARBON, CONTROL AND COMFORT
User-centred control systems for comfort, carbon saving and energy management

First results from this collaborative EPSRC-funded project showed significant variations in the internal environmental conditions across similar properties and across different spaces within these. The Centre has been working with King's College London on developing a detailed understanding of how people create and maintain thermal comfort conditions in their own homes. This has involved further comfort surveys, physical monitoring and interviews with occupants. Loughborough University has developed 'interventions' to communicate energy consumption to householders, one of which is shown Figure 1. The Centre is monitoring the impact these interventions have on people's comfort practices.

SUSTAINABLE REFURBISHMENT OF BUILDING FAÇADES AND EXTERNAL WALLS (SUSREF)

In 2011 the SUSREF project moved into the final crucial phase of monitoring five external wall constructions in North Wales, before and after different insulation upgrades were applied to them. The preliminary phase consisted of modelling temperatures and moisture contents in the walls and the proposed upgrades using WUFI 2D™ so that the behaviour of the two dissimilar materials could be analysed: the stones and the mortar joints between them. Figure 2 shows an example of the output.

Monitoring of the walls will continue until the end of April 2012.

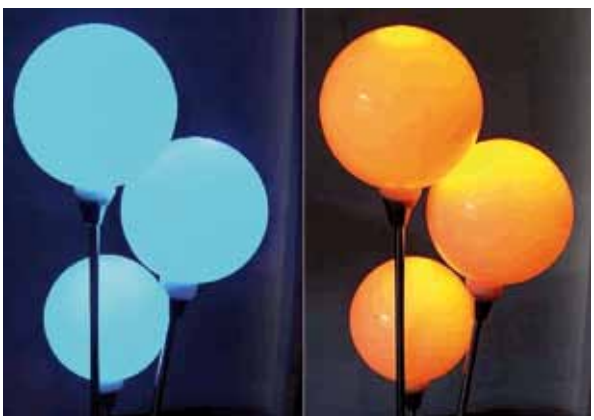

Figure 1: These lights change colour to provide visible feedback to occupants on the temperature in the room. Courtesy of Garrath Wilson, Loughborough University

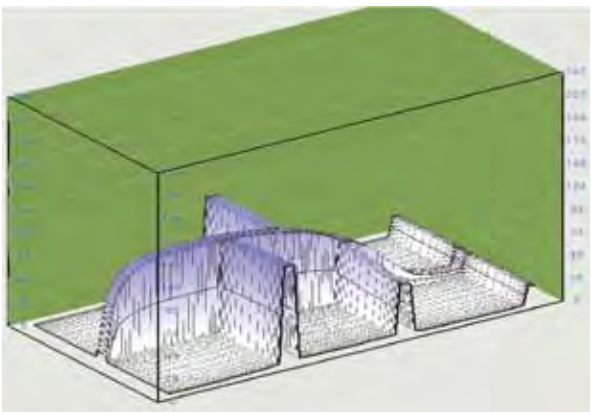

Figure 2: Snapshot of moisture content in a thick stone wall exposed to the harsh North Wales climate. Moisture moves through the mortar joints. Courtesy of Kruti Gandhi

LOW-CARBON BUILT ENVIRONMENT (LCBE)
Monitoring the performance of low-carbon technologies

The Centre leads Work Package 6 of the LCBE project and through this consolidates and extends the findings emerging from the other projects described here. A coherent set of guidelines for evaluating the performance of low-carbon buildings is being developed using these findings.

CONDITIONING DEMAND
Older people, diversity and thermal experience

This project began last year and aims to develop a better understanding of how older people adjust to the challenges of new heating technologies in their homes (Figure 3). In contrast to the *Carbon, control and comfort* project described earlier, this project focuses on private sector housing rather than social housing. It will not carry out detailed physical monitoring, but instead will consist mainly of qualitative studies of people's preferences for particular types of thermal experience. The project is jointly funded by EPSRC and EDF and is a collaboration between Manchester, Lancaster, Exeter and Cardiff universities.

BUILDING PERFORMANCE EVALUATION

Work has continued on two related Technology Strategy Board (TSB) projects in the Building Performance Evaluation programme. SuDoBE has carried out design reviews, and physical testing of two Passivhaus dwellings (Figure 4) and has secured further funding to continue monitoring of these buildings.

Figure 4: The Camden Passivhaus by Bere Architects, focus of a TSB project. Courtesy of Olivia Guerra-Santin

CO-HEATING PROJECT

Following the work carried out on the TSB-funded project to evaluate the performance of the Ebbw Vale houses, two colleagues have investigated the issues surrounding the use of co-heating techniques to assess the performance of low-energy buildings. This has led to the Centre's involvement in a project funded by the NHBC Foundation to explore different methods of conducting co-heating tests. This work is currently under way and the Centre is one of six teams engaged in measuring the performance of a pair of test houses on BRE's Watford site (Figure 5).

Figure 3: Comfort 'practices' in the home. Courtesy of Nicholas Humes

Figure 5: Co-heating setup in a low-energy dwelling. Courtesy of Shiyu Jiang

PhDS

Three students started their PhD studies in 2011 with BRE Trust support:

- Christine Suffolk
  Rebound and spillover effects: occupant behaviour after energy efficiency improvements are carried out
- Timothy Forman
  Maintenance and lifespan of low-carbon and energy-efficient retrofits in UK domestic construction (BRE-supported EPSRC CASE Award)
- Mark Waghorn
  Developing low-carbon buildings with Welsh timber (BRE-supported Knowledge Economy Skills Scholarship [KESS]).

These students are currently engaged in BRE-supported PhD studies:

- Shiyu Jiang
  Understanding the impact of occupant behaviour on energy consumption within existing homes
- Kate Knowles
  Developing effective strategies for design interventions to improve sustainability in existing urban communities
- Gabriela Zapata
  Situated learning in the context of low-carbon design (learning from low-carbon design).

For further information on any of these projects or those that follow, contact Professor Christopher Tweed,
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UNDERSTANDING THE IMPACT OF OCCUPANT BEHAVIOUR ON ENERGY USAGE WITHIN EXISTING HOMES

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SUMMARY

Indoor environment has a significant effect on occupant performance, productivity and satisfaction. Maintaining comfort demands energy and resources. In the real world, indoor environment is influenced by complexities of past comfort history, technical practices and culture. The aim of this project is to investigate the impact of occupant behaviour on domestic energy consumption within selected sustainable homes and to develop a methodology that can determine variation in energy usage caused by occupant behaviours and preferences.

BACKGROUND

The way occupants operate buildings has profound implications for the quality of both the natural and built environments[1–4]. It is commonly estimated that people in economically developed countries spend at least 80% of their time indoors. This suggests that the quality of the indoor environment can have a significant impact on comfort, health and overall sense of well-being. In an effort to maintain the quality of the indoor environment, the occupants play an instrumental role in conditioning the home to provide a comfortable environment (Figure 1). This is achieved either:

- through the way they interact with the indoor environment and building components and modify their behaviours

or

- through a change in their expectations and preferences due to contextual factors and past thermal history[5].

Multiple studies continue to be conducted internationally to collect data on occupant behaviour concerning building control systems and devices, ie how they operate fans, radiators, windows, shades, luminaires to create a desirable indoor environment. Such data can bring a better understanding of the nature, type and frequency of energy-related behaviours in buildings and thus support the development of related behaviours.

RESEARCH PROGRAMME

This project is based on field work involving the monitoring of physical conditions, energy usage and occupant behaviours within a range of Code for Sustainable Homes level 4 homes and an eco-refurbished terraced house (Figure 2). Through working closely with the occupants (Figure 3), the resulting analysis will address

Figure 1: The relations between occupant behaviour, domestic energy consumption and indoor built environment

the uncertain causes and consequences of different patterns of occupant behaviour and understand their day-to-day comfort practices. A later objective is to validate findings and develop them into a monitoring guideline and methodology package which will enable others to explore possible scenarios and estimate the implications for energy usage and building performance.

PROJECT OUTCOMES/CONCLUSIONS

There are numerous benefits to be gained from an improved understanding of the influence of an occupant's behaviour on energy usage and his/her personal comfort. This project has delivered the following outputs.

- Analysis of data from continuous energy usage and from the local climate and indoor environment of four occupied houses. The data cover one summer and two heating seasons. The data were gathered from different

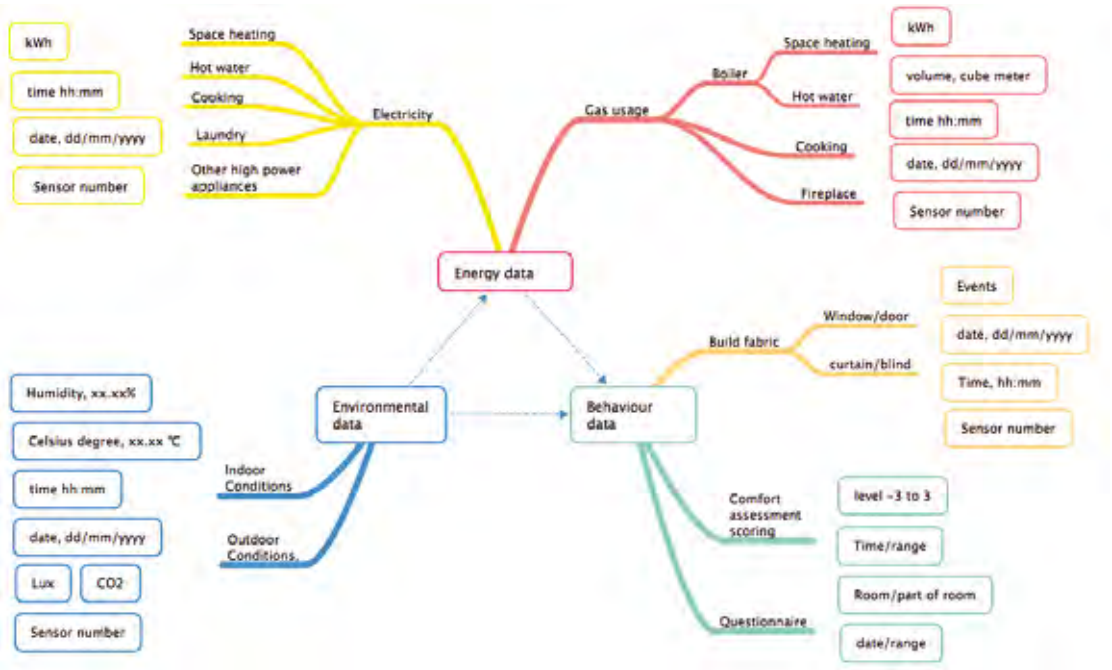

Figure 2: Overall monitoring data structure

Figure 3: Monitoring work flow

sets of occupants in identical houses and the same sets of occupants in different houses to enable comparisons of occupant behaviour and thermal comfort.

- A door/window angle sensor prototype has been developed and tested for use as an add-on sensor to provide detailed data on the performance of selected windows and doors which can have a significant impact on the thermal performance of a room.
- Data to help occupants to get the most enegy savings out of their newly upgraded houses and understand what they get in return, and to improve occupant energy use and understanding of how they have consumed the energy.
- Quantified feedback for housing associations on how tenants manage their new homes and operate new heating systems, including observations of what can be improved. Housing associations will be able to use the feedback to produce a training program for their tenants which gives the best advice on managing energy use in their homes.
- Feedback to industry which includes:
  - improved predictive models
  - more sophisticated and responsive environmental control algorithms
  - increased opportunities for personal control
  - enhanced levels of comfort and acceptability among occupants
  - reduced energy consumption.

RESEARCH OUTPUT

To date, the research output has been in the form of two conference papers. A journal article is in preparation which will give a detailed description of the door/window angle sensor design and field test.

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LEARNING FROM LOW-CARBON DESIGN

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SUMMARY

This research investigates the experience of a small number of architecture firms working on new buildings in Wales to understand the implications of increasingly demanding energy regulations on routine delivery. Few projects are being analysed to identify the techniques and routines used to embed performance into the design. The study is documenting and comparing the mechanisms adopted in projects procured by the 'Design and build' route to unveil the implementation of energy regulations from the practitioner's perspective.

BACKGROUND

The UK is committed to reducing its carbon emissions by 80% by 2050 compared with 1990 levels. The decarbonisation plan in the building sector aims for zero-carbon buildings by 2020. The reductions in new buildings have been set in three-year increments:

- 25% by 2010
- 44% by 2013
- zero carbon between 2016 and 2020.

Wales is intending to lead this decarbonisation by aspiring to higher transitional targets. In 2007, the Welsh Government announced in a policy statement the aspiration of new zero-carbon homes by 2011[1]. Detailed proposals for consultation will be pulished in 2012 and are likely to aim for a 55% reduction to be implemented in 2013. As the Welsh industry adopts more demanding energy regulations, barriers to achieving policy intentions have been identified, highlighting the need to engage and support the industry in delivering low-carbon buildings. The process of developing skills, knowledge and supply for technologies and products to achieve the mandated carbon level is estimated by the European Council for an Energy Efficient Economy (ECEEE) to take 10–15 years[2]. Research suggests that the construction sector will have to develop skills, acquiring understanding of relevant technologies and the practical implications of carbon reduction during the transitional periods towards zero carbon[3–7]. In this context, real time development of few projects is being analysed to identify the mechanisms used by practitioners to embed energy considerations in the projects that they design and deliver.

RESEARCH PROGRAMME

The research was divided into two phases:

- exploratory interviews
- project analysis.

During the first phase, more than a dozen practitioners were interviewed to discuss their views about:

- low-carbon policy agenda
- regulatory instruments
- supporting mechanisms to facilitate low-carbon delivery.

The challenges, opportunities and difficulties perceived by the interviewees were identified and further investigated during the second phase. The project analysis comprised:

- immersion in four architectural practices to study how practitioners adopt low-carbon standards
- guidance
- impact of official regulation on the fluidity of the delivery process.

Using an ethnographic approach, the researcher:

- analysed project documentation
- shadowed the architects as they worked
- attended project meetings to investigate the mechanisms used during design and delivery of projects.

Although the study was focused on the work of the architect, other team members such as mechanical engineers, energy consultants and BREEAM assessors also participated in the research. The process of defining energy indicators in the projects was documented to identify mechanisms that inform low-carbon design. Routines and informal techniques grounded in the fluidity of the process and preferred by practitioners were analysed in the light of the regulations to enforce carbon reductions. Special attention was made to practitioners' deployment of policy mechanisms such as the Approved Document Part L2A, Conservation of fuel and power[8], BREEAM[9] and the simplified building energy model (SBEM)[10]. The data are being collated in relation to the

RIBA Plan of Work. The findings are analysed in the light of Communities of Practices research that identifies the significance of the social fabric and informal processes in problem-solving environments[11–13].

PROJECT OUTCOMES/CONCLUSIONS

Disparities between the practitioners' perspective and the policy dimension were found such as:

- cycles of organisational learning versus legislative transitional periods
- project drivers versus policy agenda
- fragmentation between design and construction phases.

Mandatory requirements are perceived to be key to achieving the low-carbon policy agenda. Due to higher targets, practitioners are adapting their ways of working and new forms of practice are likely to emerge. Practitioners are using a variety of informal techniques, tools and routines to understand, assess and inscribe the energy targets in the design and achieve carbon reductions.

There is a preference for the use of heuristics, experience and collective knowledge in defining, understanding and negotiating the energy target during the design process. As the conceptual design is reached, quantifying methods are deployed for evaluating energy performance and verifying compliance with mandatory standards. However, heuristics and experience-based techniques remain in use throughout the process, during both conceptual and detailed design.

In buildings procured by the 'design and build' route, practitioners involved in the design phase have to make explicit the carbon target and transfer the energy rationale of the design to the team that delivers the project on site.

Low-carbon processes are likely to require the inclusion and integration of performance considerations in the earlier stages of project development.

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FIRST-YEAR PhD PROJECTS

BRE Centre of Excellence in Sustainable Design of the Built Environment, Cardiff University

REBOUND AND SPILLOVER EFFECTS: Occupant behaviour after energy efficiency improvements are carried out

Christine Suffolk

Background

The UK government has set targets to reduce carbon emissions by 80% (from the 1990 baseline) by 2050[1]. Domestic dwellings in 2007 accounted for 25 to 27% of CO_2 emissions and 87% of the buildings that will be standing in 2050 already exist[2]. Researching occupant behaviour in existing domestic buildings will contribute to our understanding of how these targets can be achieved.

To achieve these targets, improvements in the energy efficiency of existing buildings are being carried out. Although the energy intensity of industrial economies fell before the start of the recession in 2008, the absolute energy use attributed to UK households (and associated CO_2 emissions) continued to increase[3]. One contributor to this failure to reduce energy consumption is that occupants 'take-back' some of the potential energy savings as additional comfort. For example, occupants might choose to heat their homes at a higher temperature or for longer periods of time after installing insulation because the cost per square metre to heat their home has fallen[4].

As well as the take-back or 'rebound effect', this research will also be evaluating positive and negative behavioural 'spillover'. Positive spillover occurs when the adoption of a particular pro-environmental behaviour increases the likelihood of a person adopting another pro-environmental behaviour. In contrast, negative spillover occurs when the likelihood of adopting another pro-environmental behaviour recedes[5].

Objectives

The main aim of this research is to investigate the rebound and spillover effects of occupant behaviour in domestic dwellings after energy efficiency improvements have been carried out. The research programme will comprise:

- evaluation of behavioural spillover using qualitative and quantitative research methods
- evaluation of rebound effects by taking physical measurements and collecting data using questionnaires
- evaluation of behavioural processes underlying and contributing to spillover and rebound
- investigation of the effect that energy efficiency advice has on rebound and spillover.

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EVALUATING DOMESTIC RETROFITTING FROM A WHOLE-LIFE PERSPECTIVE

Tim Forman

Background

Sweeping changes in new construction in the post-war, inter-war and earlier eras transformed British housing dramatically in their time. Current retrofitting practices promise to transform housing with equal impact again. Projections suggest that 80% of 2050 housing already exists[1]. Given that the UK housing sector currently accounts for approximately 29% of final energy use[2], it is clear that unprecedented action is needed if the national target of an 80% greenhouse gas reduction by 2050 is to be achieved. Government policy, building regulations, and funding structures are aligning to drive dramatic improvements in the energy performance of existing housing.

Concerted action is required to reduce the gap between targeted levels of improvement and actual performance in as-built and in-use construction. Opportunities exist for improvements in:

- the costing of retrofits and prediction of their operational performance
- the delivery of retrofits and refurbishment to high standards of energy performance
- regulatory reform built on industry feedback.

Together, these improvements can ensure that progress towards carbon reduction goals is cost-efficient and is made in real, rather than notional, steps.

Research context

- Whole life costing assesses realities which are hidden by conventional capital cost-based analysis. Post-installation costs in domestic construction outweigh capital costs significantly; ratios given in the literature vary widely but suggest a ratio of roughly 5:1. Recent changes in the Energy Performance of Buildings Directive (EPBD)[3] require that life-cycle costing and whole life costing be incorporated in the drafting of new standards by member states. To date, however, whole life costing has not been adopted widely in domestic retrofitting and refurbishment practices. The reason for this lies in its complexity and the limited data and resources to support it, and in the tendency of grants and incentives to influence retrofit strategy. Whole life costing relies on predictions of performance, expense and income ratios, and risk. To increase the use of whole life costing, improved understanding of retrofits as they are actually built and used is needed.
  By developing our understanding of post-installation realities, value from investment can be optimised. This will be reflected not only in more informed specification of strategies, but also in improved installation, operation and maintenance practices. To optimise the value of retrofitting investments it is necessary to synthesise knowledge of the following factors:
  - knowledge about materials
  - technologies
  - installer practices
  - supply chain characteristics
  - occupant behaviours
  - interplay of regulations and policy.

When professionals, policy makers and end-users begin to think in 'whole life' terms, investment promises better results.

- The gap between designed energy performance and as-built construction and operation is a well-known problem in the industry. Builders, designers and policy-makers, as well as supply chain participants, occupants, and scientists, can each make contributions here. Significant opportunities exist to increase knowledge exchange and to develop best practices. Reducing emissions from existing buildings is a highly complex task and one that requires dedicated study and continual improvement. Understanding the impact of buildability and learning rates, of complications in procurement and delivery, and of post-installation realities can help to improve best practice and strengthen progress towards energy efficiency and emissions reduction.
- Retrofitting and refurbishment is undertaken in response to disparate forces including:
  - household financial saving
  - improvement of housing quality
  - incentive programmes addressing climate change, fuel poverty, skills development, job creation and economic stimulus.

  Owners and social landlords do not tend to follow neat, rational hierarchies of approach to reducing energy use and emissions. Instead, strategy and decision-making respond to changing drivers. Policy built on this knowledge can align retrofitting and refurbishment with cost-optimal approaches as measured in real terms.
- Building regulations, too, shape much of the progress towards an energy-efficient future for existing buildings. It is important, therefore, that they respond both to the forefront of science and to the characteristics of the trades and industries which they affect. By ensuring that future revisions of building regulations are informed by academic research as well as by feedback from 'on the ground', their effectiveness and practicability will be assured.

Billions of pounds will need to be spent to improve UK housing stock in line with the 2050 emissions reductions targets. In view of the scale of investment, and of the importance of actually meeting these targets, it is imperative that investment in the sector is optimised. To best deliver upgrade projects, decision-making frameworks and professional practices need to be adopted that place as-built and in-use performance and whole life cost at the centre of considerations.

Objectives

This research project will study the complexities of retrofit and refurbishment projects and the influences on their operational performance and whole life cost. The project will comprise:

- a literature review to develop a comprehensive understanding of the many factors at play including political, regulatory, organisational, technical and scientific topics.
- investigation of the interplay of design, materials, installer practice, and operation against this broader backdrop of issues using a mixed-methods approach to research, and drawing on qualitative and quantitative techniques.

This research will make a contribution to:

- more informed retrofit strategies and optimisation of their value
- improvements in policy and regulation.

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DESIGN

LIGHT TRESPASS AND THE PLANNING PROCESS

Paul Littlefair and Stephanie King

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SUMMARY

Existing guidance on light pollution available to planning officers was reviewed to identify areas of conflict between guidance and issues not yet covered. New calculation methods were devised to quantify and assess light spill from the windows of new developments, and to resolve a problem with existing assessment methods for distant floodlights. A BRE Digest was drafted to bring together existing guidance and introduce the new calculation methods.

BACKGROUND

Unwanted artificial light can affect both near-neighbours as light trespass, and the wider environment as light pollution that creates sky glow and makes it impossible to see stars. Although unwanted light is a statutory nuisance under the Clean Neighbourhoods and Environment Act 2005[1], this legislation deals with light which is already installed so is limited in the kind of problems it can address, ie light must come from one premises and affect another. It therefore does not cover sky glow.

Planning officers have a key role in determining whether a new development should proceed and there is currently no Planning Policy Guidance or Planning Policy Statement on artificial light to support them.

Although the number of publications available on the subject is large, they tend to refer to the same core documents which contain numerical guidelines:

- CIE Technical Report 150[2]
- ILP (formerly ILE) guidance on obtrusive light[3].

Two other sets of guidance are less commonly referenced:

- BS EN 12464-2[4]
- CIBSE Factfile 7[5].

Some qualitative guidance is available in an out-of-print document, *Lighting in the countryside*[6], now available online from the UK Government's Department for Communities and Local Government (DCLG).

The review revealed these areas of concern:

- inconsistencies within guidance on the acceptable exterior light levels in different areas
- light spill from windows, ie will a heavily glazed building produce enough light to disturb an existing resident in a neighbouring dwelling?
- difficulties with the current assessment method with reference to distant floodlights.

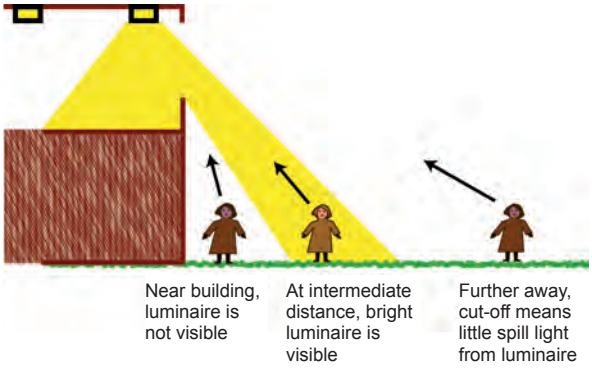

Figure 1: Schematic drawing showing zone of light spill from an office building. Light spill is greatest at angles of 30–45° from the vertical

RESEARCH PROGRAMME

BRE reviewed existing guidance on obtrusive light to establish areas which were either not covered effectively or where there was disagreement between documents. The issues, which were not fully addressed by the numerical guidelines, included:

- *numerical criteria for uplighting:* practical advice was given in the guidance, but there were no numerical limits with which to assess the acceptability of a proposal
- *different criteria were given for different environmental zones depending on whether the site was urban or rural*. Sites may be characterised by more than one zone, for example, a town or village in a national park may fall into two categories, E1 and E3
- *light spill from windows:* would a heavily glazed building produce enough light to disturb an existing resident in a neighbouring dwelling? (Figure 1)
- *unintended building luminance,* ie where light reflects from an object such as a building, adding to the total spill light from the site
- *colour of lighting:* would white light be more or less obtrusive than coloured light?

Figure 2: A problem with current guidelines based on the intensity of floodlights is that no allowance is made for the distance of the source

A workshop was held at BRE to ask planning officers for their opinion on these issues and to determine what extra guidance was needed. The consensus was that new guidance needed to:

- be written in layman's or planner's terms and be easy to understand
- address inconsistencies in current guidance because inconsistencies render planning decisions vulnerable to appeal.

Development of calculation methods

Light spill from windows

New calculation methods were developed to deal with light spill from windows. This was supported by a project partner responding to a concern raised by a planning officer.

Light output from floodlights

Existing calculation methods were adapted to address an issue with the way that light output from floodlights is assessed (Figure 2). In existing guidance, the luminous intensity of individual luminaires is considered, a method which does not consider light attenuation with distance. An alternative methodology was suggested which replaces this consideration with that of received light, which will better address the actual impact of a distant floodlight.

PROJECT OUTCOMES/CONCLUSIONS

- Significant issues were found with the guidance given in *CIBSE Factfile 7*[5], and it is now under review for revision or withdrawal.
- New assessment methods were introduced to address issues which were not previously capable of being assessed despite being raised as issues of concern in planning applications.
- Helpful guidance in lay terms was issued to deal with a subject where many planners have minimal experience and may find themselves at a disadvantage when faced with a planning application where exterior light is a contentious issue.
- Findings from the project have been included in Green Public Procurement criteria for street lighting which is being developed by BRE for the European Commission, and will be incorporated in forthcoming CIBSE publications on external lighting.

Figure 3: Luminaire fitted with a screen to limit spill light reaching a nearby garden

RESEARCH OUTPUT

A BRE Digest, *Obtrusive light from proposed developments,* which explains light trespass and light pollution in lay terms and directs the reader to additional information and guidance will be published by IHS BRE Press in 2012. It elaborates on some of the common areas of misconception and error which lead to poor lighting installations, and will assist planners who need to review a submitted lighting design and judge its acceptability.

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MEASURING THE WELLBEING BENEFITS OF INTERIOR MATERIAL SELECTION

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SUMMARY

This project is original in that it brings together work on different building materials in terms of the wellbeing of end-users beyond the scope of indoor air quality: wellbeing that building occupants perceive as a result of what surrounds them and the materials that have been used in the built environment.

The objective for this project was to put occupants at the centre of the sustainable refurbishment of buildings. The data collection tool v.1 and *Five Golden Rules* guide which have been developed enable decision-makers to choose materials in refurbishment and re-fit projects that will support the wellbeing of occupants.

There has been immense interest in this project with respect to hospitals, schools, offices and beyond (eg social housing providers).

BACKGROUND

In the last decade, the construction industry has promoted the 'Latham' and 'Egan' initiatives for removing conflict, bringing about changes and shaping the way design and construction work is procured and managed. Refurbishment construction projects are increasingly under pressure to focus on the estates and organisation's strategic and business needs as well as operational performance. There seems to be a growing need to take a stepwise approach to developing accord between the business aspirations of the organisation and the ability of the estate to support it (ie effective corporate real estate (CRE) management). This is illustrated by an increase in organisations using post-occupancy evaluation (POE) and similar tools such as BREEAM-in-Use to provide a feedback loop throughout a building's life cycle from initial concept through to occupation.

There is a large body of evidence demonstrating that the workplace environment has an impact on performance. However, most research into workplace impacts on wellbeing has focused on the indoor environment (eg thermal comfort, lighting, indoor air quality) and acoustics with little emphasis placed on the actual materials used. The main project challenge was therefore to address a critical gap in knowledge about the integration of wellbeing benefits into the selection and specification process for interior materials choices.

Figure 1: Materials and wellbeing in the built environment as perceived with all five senses

RESEARCH PROGRAMME

The project's aim was to:

- develop a tool that:
  - utilises quality data where it exists (collected through desk research and various techniques such as focus groups, interviews, online survey, POE)
  - collects new data with specific reference to end-user wellbeing
  - delivers a prototype selection optimiser or WISER* manager (ie data collection tool) and *Five Golden Rules* guide.

* Wellbeing – Improving the Satisfaction of End-users in Refurbishment (the project's strapline)

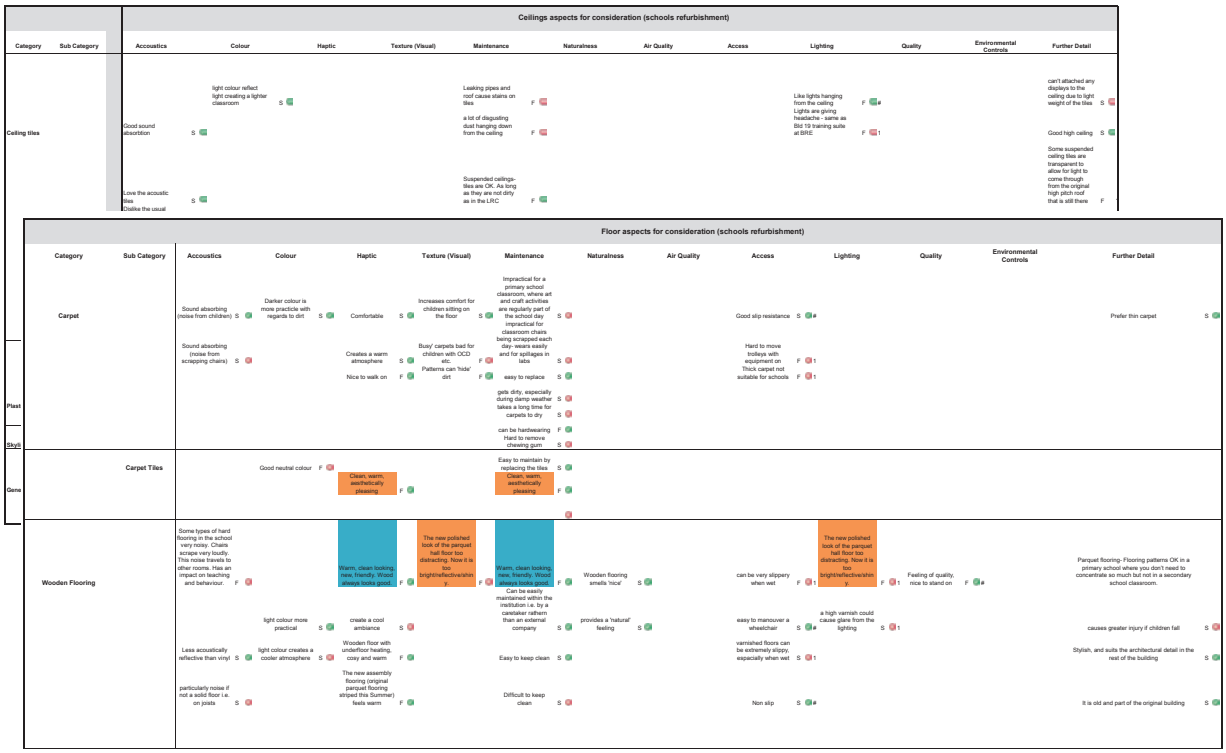

Figure 2: Sample pages from the alpha version of the WISER data tool

- facilitate the selection of low-impact materials with reduced emissions to air for healthy buildings
- establish the state-of-the-art for wellbeing benefits of interior materials including touch (haptic), warmth, coolness, relative humidity and light via:
  - a wide-ranging literature review
  - interviews and focus groups in offices, schools and healthcare buildings and sensory testing
  - capture of information via online survey and in-situ workshops on the properties of materials
  - development of:
    - a database of the wellbeing properties of materials
    - a tool that will inform designers about the benefits of material section from the perspective of wellbeing.

PUBLICATIONS/RESEARCH OUTPUT

The tool and guide developed during this project provide added value for clients in evaluating options for materials in re-fit and refurbishment projects in terms of the wellbeing of end-users. The alpha version of the WISER tool (Figure 2) for data capture holds all collected information in a central location and enables multiple ways of manipulation for end-users. The accompanying *Five Golden Rules* guide (Figure 3) discusses:

- the multifaceted nature of the topic, the complexity of solutions and their interrelatedness
- the end-users and their wellbeing
- the background to the development of the guide
- the five golden rules to think about:
  - regulation and published guidelines (including safety, environmental performance, etc.)

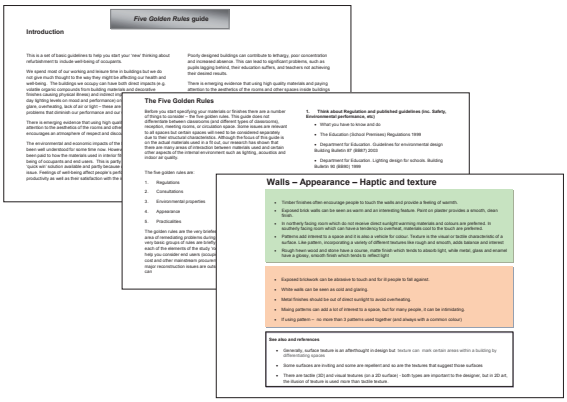

Figure 3: Sample pages from the *Five Golden Rules* guide

- consultation with a range of stakeholders
- environmental properties
- appearance (eg haptic and texture)
- practicalities (eg access).

More information about the findings of this research project will be given in a BRE Information Paper which will be published by IHS BRE Press in 2012.

Further development and population of the tool and guide is needed in order to cover the entire process of refurbishment from inception to operation. The tool also needs to be piloted at these different stages and more in-depth guidance developed for its use.

For further information, contact Katie Livesey,
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BRE CENTRE OF EXCELLENCE IN SUSTAINABLE ENGINEERING, CARDIFF UNIVERSITY

Yacine Rezgui

Professor, Engineering Informatics

2011 has been a hectic but successful year for the BRE Centre of Excellence in Sustainable Engineering. The Centre has increased its PhD base and currently has 39 registered PhDs researching in areas ranging from sustainable self-healing concrete to BIM-based computational simulation of buildings. The Centre has this year graduated two PhD students:

- Michael Dibley for *The digital building: from conceptual design through to life-long management*
- Iulia Carmen Mihai for *Micromechanical constitutive models for cementitious composite materials*.

The Centre was awarded four new contracts:

- TSB: *RegBIM: BIM-based regulatory compliance design environment*
- EU FP7: *Knowledge-based energy management for public buildings through holistic information modelling and 3D visualisation*
- EU FP7: *Renewable, storage and ICT, for low carbon intelligent energy management at district level*
- TSB: *Finite element modelling of structures under earthquake loading*.

The CloudBIM (EPSRC) project, *Exploring the feasibility and potential for cloud research in the architecture, engineering and construction sector,* was completed.

The Centre has organized and hosted a number of events, including the Heat & Moisture in Buildings Conference, 4–5 October 2011, led by Christina Hopfe.

In terms of publications, the following are highlights:

- Professor Rezgui has coauthored with John Miles, *Harvesting and managing knowledge in construction: From theoretical foundations to business applications*. It was published by Spon Press in April 2011.
- Dr Li, Professor Rezgui and Professor Rana are editing a special issue of the Elsevier journal of *Advanced Engineering Informatics* entitled *Special issue on Distributed data management in the architecture, engineering and construction industry*.
- Several papers on building energy have been accepted in high-impact factor journals, including:
  - Wilson I and Rezgui Y. Barriers to construction industry stakeholders' engagement with sustainability: Toward a shared knowledge experience, technological and economic development of economy. 2012. (Elsevier – Impact Factor: 5.6).
  - McLeod R S, Hopfe C J and Rezgui Y. An investigation into recent proposals for a revised definition of zero carbon homes in the UK energy policy (Elsevier – Impact Factor: 2.6).

For further information on any of the projects that follow, contact Professor Yacine Rezgui,
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CLOUDBIM: Exploring the feasibility and potential for cloud research in the architecture, engineering and construction sectors

Yacine Rezgui, Thomas Beach and Omer Rana
BRE Centre of Excellence in Sustainable Engineering, Cardiff University

SUMMARY

The CloudBIM project, funded by the Engineering and Physical Sciences Research Council (EPSRC), has explored the feasibility and potential for utilising cloud computing capability to address data storage and processing needs of stakeholders in the architecture, engineering and construction sectors, specifically focusing on Building Information Modelling (BIM).

The CloudBIM project involved a large-scale industry consultation with professionals from several key industry disciplines across a variety of companies (ranging from small architectural practices to large multi-national organisations). This has enabled us to ensure that the findings of the project have industry relevance and are able to adequately assess stakeholders' views about outsourcing BIM to a cloud computing platform.

From the work undertaken, cloud computing would appear to offer a unique opportunity to solve the architecture, engineering and construction industry-wide data-sharing, access and processing requirements. However, key socio-organizational issues related to the project-based nature of the industry must be resolved.

BACKGROUND

Building information modelling

The architecture, engineering and construction (AEC) industry is a highly fragmented, data-intensive, project-based industry that depends on a large number of different professions and firms. It has strong data-sharing and data-processing requirements across the building life-cycle, from concept design to demolition. The process of designing, re-purposing, constructing and operating a building involves not only the traditional disciplines (Architecture, Structure, Mechanical & Electrical, etc.) but also many new professions in areas such as energy, environment and waste with large data-sharing requirements.

In this context, data management across the project life-cycle tends to be fragmented with a lack of policy on overall data management. Recently, efforts have been invested to identify data requirements at different life-cycle stages in order to allow a more effective exchange of data between software applications across the life-cycle of a building facility. This process of generating and managing building data across its entire life-cycle has become known as the Building Information Model (BIM)[1].

Improving industry adoption of BIM is currently a major area of research in both industry and academia, driven by the UK Government's requirement that publicly funded projects should adopt 'fully collaborative 3D BIM as a minimum by 2016'[2].

Cloud computing

Cloud computing is defined by the US National Institute for Technology Standards as a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction[3]. In short, it allows users to utilise dynamically a pool of either storage or processing resources.

Cloud computing has already achieved widespread success through the adoption of consumer applications such as Google Docs and Dropbox. Within the AEC sector, some software companies are already beginning to utilise cloud computing within their projects and an example of this is ProjectWise from Bentley Systems, which utilises Microsoft's Azure cloud computing system[4].

RESEARCH PROGRAMME

The CloudBIM project has the following objectives.

- Investigate the feasibility, benefits and limitations of using cloud computing capability to support data storage outsourcing for BIM project data.
- Develop a governance model for outsourcing BIM data taking into account stakeholders' privacy, security, ownership, and intellectual property rights across the building life-cycle.
- Specify and implement a CloudBIM proof of concept cloud prototype.
- Identify the 'Governance–Performance' benefits and costs of storing BIM data across virtualized data storage capability made available over the cloud, focusing on three key metrics:
  - network overheads in using externally sourced, virtualized storage
  - economic costs associated with utilizing such capability
  - privacy constraints associated with utilizing such storage for business sensitive data, as viewed by industry end users.
- Devise a strategic research roadmap for the exploitation of the CloudBIM platform by the AEC research community.

In undertaking this project, a key focus was to ensure that any solution created is industry-relevant. To do this, we undertook a detailed process of industry consultation with the assistance of the Modern Built Environment Knowledge Transfer Network (MBEKTN).

Our consultation utilised a qualitative approach involving two deliberative workshops (which have attracted 72 industry representatives) and four focus group meetings (with a total of 20 participants) incorporating qualitative methods of inquiry over five months (February to June 2011). In this process, the initial workshops fed into the second set of smaller focus groups so that the governance model being developed could be incrementally improved.

In addition to utilising the research from consultations, best practice was drawn in from the industry by examining relevant standards, ie BS1192:2007[5] and current BIM server technology (namely, ProjectWise from Bentley Systems[4]).

The technical development of the CloudBIM cloud computing prototype utilised the CometCloud cloud computing framework[6] from Rutgers University (USA). Using this framework, a proof of concept prototype has been developed, this prototype has been integrated with Google Sketchup and and it has been evaluated on the basis of functionality and its ability to perform sucessfully using an industry-relevant case study.

PROJECT OUTCOMES/CONCLUSIONS

There have been four key outcomes resulting from the CloudBIM project:

- Development of a governance model for BIM data based on detailed industry consultation. This involved the categorisation of data and relationships within a BIM (Figure 1), and then the development of an access control framework to meet the requirements of the AEC sector.

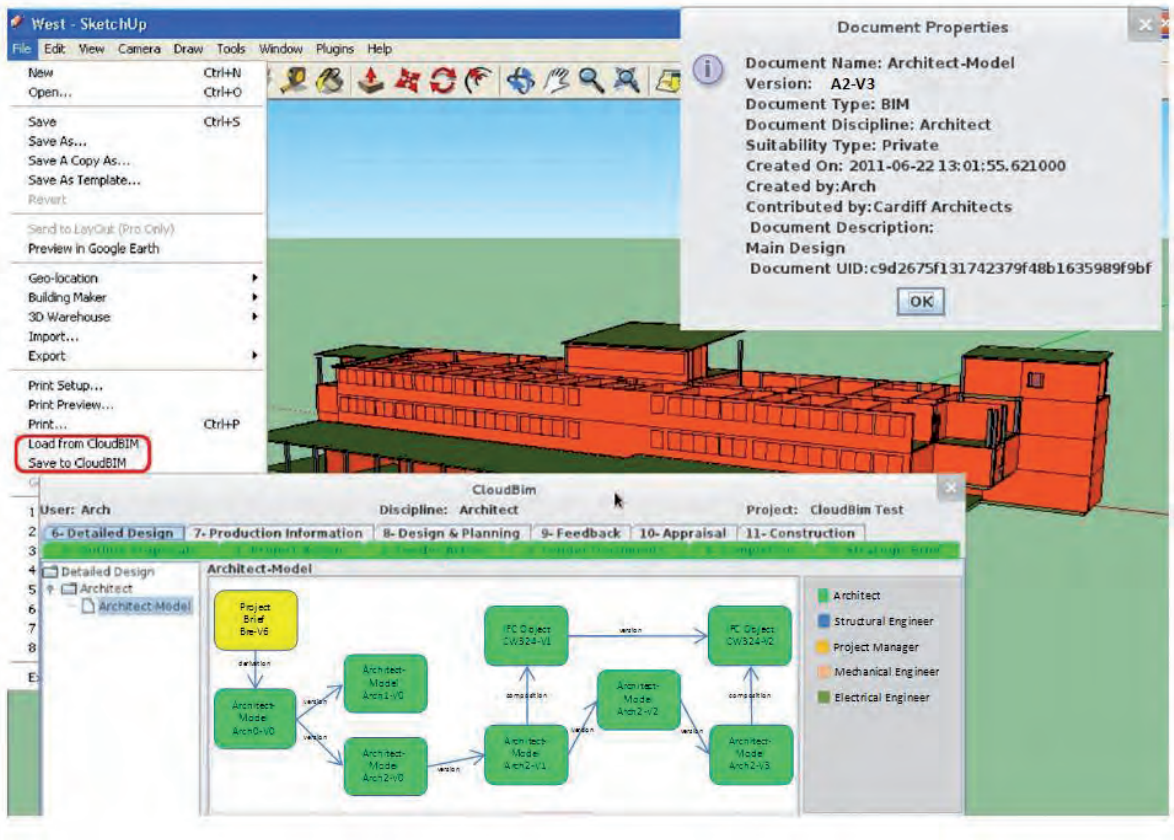

Figure 1: CloudBIM CAD interface

- A proof of concept cloud computing prototype, which has been integrated with Google Sketchup (Figure 2).
- An analysis of governance–performance benefits.
- A research roadmap aimed to assist the AEC community (academic and industrial) in moving towards the UK government 2016 BIM compliance goal[2].

CloudBIM provided a means of exploring some of the technical and non-technical issues related to the storage of BIM data into a cloud computing environment. This has led to the development of a research roadmap for BIM (illustrated in Figure 2).

Unsurprisingly, the majority of the barriers to the adoption of cloud-based BIM have been related to the required adaptation of industry processes to the use of BIM, regardless of whether it is backed by cloud storage or not, and ensuring that the design of a system is in compliance with complex industry requirements.

RESEARCH OUTPUTS

Our prototype cloud computing system, having integration with Google Sketchup was presented as a short paper and demonstration at the UK eScience *All Hands Meeting*. At this meeting, positive feedback was received and this work is currently under review in the *Transactions of the Royal Society Journal*.

Additionally, a short paper describing the prototype client and integration with Google Sketchup was presented at the CIB Computer Knowledge Building conference W078, Information Technology for Construction, in 2011.

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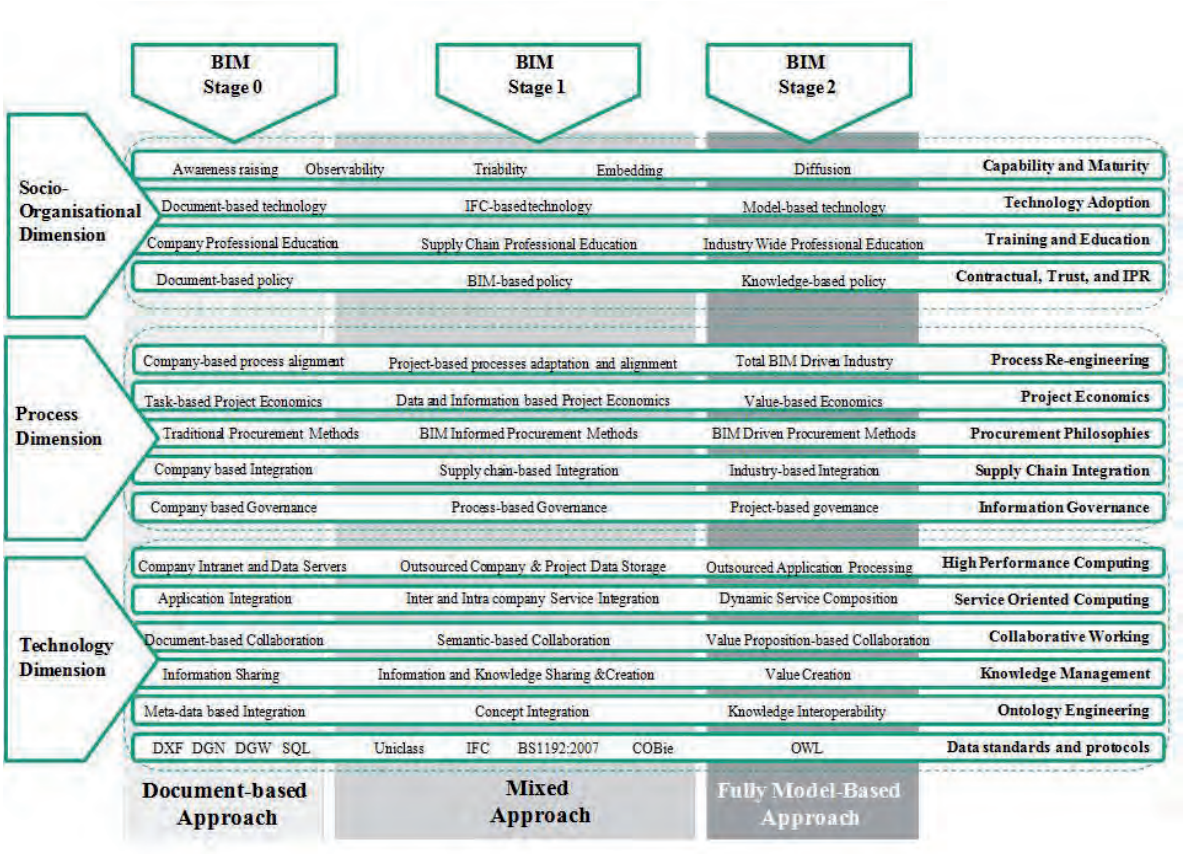

Figure 2: BIM research and development roadmap

INTELLIGENT CEMENTITIOUS COMPOSITES

Toby Hazlewood, Robert Lark, Tony Jefferson and Diane Gardner

BRE Centre of Excellence in Sustainable Engineering, Cardiff University

SUMMARY

This project aims to bring together two enabling technologies that will not only address the issue of more-for-less, but also deliver a new paradigm for the design of critical, high risk structures. What is proposed is an 'intelligent cementitious composite' that is both self-diagnosing and self-healing.

Traditionally, the resilience of the UK's built environment has been achieved by using 'robust' design procedures that focus on defining safety factors for individual elements and redundancy against adverse events. As such, construction materials are designed to meet a prescribed specification; material degradation is viewed as inevitable and mitigation necessitates expensive maintenance regimes.

This project offers the opportunity to develop a material comprising natural, geopolymer binders, manufactured aggregates and recycled polymer fibres that has the ability to adapt and, when combined with embedded radio-frequency technology, to diagnose its condition and respond intelligently to its environment. This fundamental change facilitates the creation of both a 'smart', self-healing material and intelligent, self-compensating structures.

BACKGROUND

In the UK, the overall annual spend on construction is approximately £80 $\times$ 10^9 of which almost one half is spent on repair and maintenance[1]. This is but one of many indicators that more durable construction materials are required. The most widely used group of materials in construction are cementitious composites, such as concrete and mortar. While in many respects these have served the construction industry well, they nearly always contain cracks, and it is these cracks that so often lead to the durability problems, such as reinforcement corrosion, which have necessitated this high expenditure on remediation. This is still considered valid, not-with-standing the fact that certain historical flaws have exacerbated the current situation.

The production of 1 tonne of cement produces approximately 600 kg of CO_2, which equates to approximately 100 kg of CO_2 per tonne of concrete[2]. Any reduction in the 12 million tonnes of cement used in the UK each year, or 2.35 $\times$ 10^9 tonnes used worldwide, would therefore have significant environmental and economic benefits. The fact that the production of cement is such a large contributor (approximately 5%) to global CO_2 emissions has also reached the public consciousness[3]. The development of the proposed new material system, which will lead to more efficient and sustainable use of cementitious materials, is thus timely and significant.

There have been recent research initiatives aimed at developing materials with improved resilience and self-healing abilities. Dry investigated a self-healing system for concrete which comprised tubes and/or capsules filled with adhesives[4, 5]. Jonkers and Schlangen are developing a cementitious material with embedded bacteria that produce calcium carbonate that can fill and heal cracks[6]. Schlangen has explored autogenous healing in young concrete and found that relatively low compressive stresses, of the order of 0.5 MPa, across cracks, enhances their ability to heal[7]. The ability of open cracks to self-heal is also known to depend upon the crack-width, with a value of 0.1 mm being the value below which cracks readily heal[8].

Previous investigations have explored the use of shape memory alloy (SMA) bars to replace prestressing tendons[9, 10]. These were shown to be effective at providing prestress in concrete elements but their relatively high cost makes their use in this context unviable for all but the most specialised applications. A system combining SMA wires and brittle fibres containing adhesives has also been explored recently[11].

An alternative novel approach, explored by the academics from Cardiff, is to embed shape memory polymer (SMP) tendons in cementitious matrices with the aim of creating a material system which can close cracks or prevent cracks from occurring. SMPs are far less expensive than SMAs but in standard form SMPs often develop relatively low 'recovery' or 'shrinkage' stresses when undergoing the shape transition under restrained conditions[12]. However, work done to date has proved that it is possible to find materials in which the shrinkage

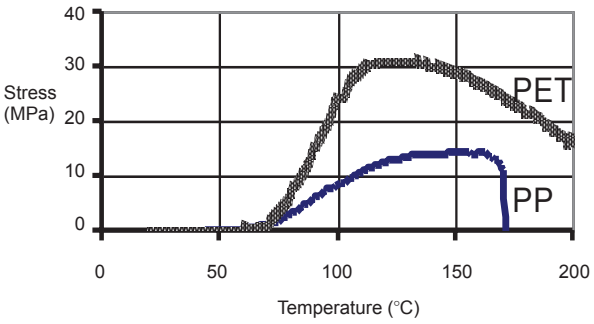

Figure 1: PET tendons testing graph

stress level is sufficient to provide an inbuilt mechanism for closing cracks.

Calculations suggested that if eccentric tendons were provided at 2% of the gross concrete area, a stress of approximately 10 MPa in the tendons would be sufficient to generate a stress of 0.5 MPa across the crack surfaces, this being the stress for self-healing enhancement suggested by Schlangen[7]. As seen in Figure 1, the PET tendons tested to date far exceeded this value, although there were concerns that the temperature value at which the peak stress occurs may cause damage to the cementitious material. A significant number of small-scale tests have now been undertaken to demonstrate the viability of this crack closure system.

To further this work, there is a need to 'up-scale' the product, identify thermoplastics that have significantly higher shrinkage stresses and develop activation mechanisms that are triggered by the response of the cementitious matrix to its environment. It is intended that the latter will be achieved by the use of embedded sensor technology that will be developed in association with BRE, making the composite a truly 'intelligent' material.

METHODOLOGY

The use of sustainable components has been proven individually, but they have never been combined and developed as a practical composite material. This project will:

- develop design and analysis models for the material
- include an experimental programme that will be used to verify these models
- develop a prototype to demonstrate its exploitation both as a replacement for traditional components and in innovative applications where the requirements of durability are paramount.

Self-healing processes in cementitious materials involve the interaction between several physical and chemical processes. This includes hydration, moisture diffusion, heat transfer, micro-cracking, macro-cracking, diffusion of pozzolanic chemicals and crack healing. In addition, the mechanical behaviour of the cementitious material itself is highly time-dependent and it is essential to simulate both creep and shrinkage phenomena in a model of a self-healing system.

The numerical framework to model the proposed composite will involve a coupled chemo-thermo-hygro-mechanical finite element approach. Chemical potentials are required to simulate strength development and/or re-healing and these need to be coupled to both heat flow (to model heat generation during hydration), mechanical and fluid flow properties. A micro-mechanical approach will be adopted for the mechanical response as this naturally allows coupling with flow properties and provides information on micro-crack formation that can be used to derive permeability tensors. Macro-cracks will be considered as strong discontinuities.

The model must also include a time- and temperature-dependent component for the shape memory polymer. A one-dimensional temperature-dependent rheological model has been recently developed which will form the basis for the work here[13], but this now needs to be extended to include both its long-term and multi-axial behaviour.

The development of a comprehensive finite element modelling tool for these processes is a considerable challenge but provides much scope for exciting, academically demanding, research that will complement the experimental programme and facilitate the prototype development.

CURRENT PROGRESS

The initial phase of the PhD studentship has involved an investigation into the time-dependent properties of the SMP employed in the SMP cementitious system. A previous student developed a rheological model for the transient thermo-mechanical behaviour of this material based on a detailed experimental investigation. This model and the tests performed involved relatively short timescales and only considered one-dimensional behaviour.

The present project has taken the existing work as a starting point and has extended it to investigate the longer term transient behaviour of the system. This has involved a theoretical extension to the rheological model and the design of an experimental apparatus to obtain test data over longer periods of time. The experiments commenced in late February 2012 and should answer the important question of whether the prestressing provided by the SMP elements significantly relaxes over time. In addition, work has begun on a multi-axial model which will apply the principles of the one-dimensional rheological model to two- and three-dimensional cases. This is considered important because the lateral behaviour of the stressed elements within the cementitious composite affects the design and performance of their anchorage and bond.

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KNOWLEDGE RESOURCE

REFURBISHMENT PORTAL

Toby Balson

Building Futures, BRE

SUMMARY

The National Refurbishment Centre's 'Refurbishment Portal' is a free web tool which provides users with information related to the cost of housing retrofit activities and associated carbon and energy savings. It currently includes over 150 case studies, as well as related graphs and data. The database offers the facility for registered users to upload their own projects, and will continue to grow in size as further information is added.

The project was jointly funded by the BRE Trust and the Technology Strategy Board, and received key support from the Energy Saving Trust and AECB, the sustainable building association.

BACKGROUND

The Refurbishment Portal was inspired by the various internet comparison websites such as GoCompare.com and MoneySupermarket.com. The aim of creating this web tool was to bring together existing knowledge from partner projects between BRE, Energy Saving Trust (EST), AECB (the sustainable building association) and the National Refurbishment Centre (NRC) (over 750 refurbishment projects in total) to demonstrate the cost and carbon effectiveness of refurbishment measures across a variety of situations.

The portal allows users to search for project case studies which match their situation but it is not intended to provide pre-determined solutions. Our aim was to create a user-friendly system which would allow users to:

- browse existing projects
- see clearly the successes and areas of difficulty in each
- draw their own conclusions.

This approach was chosen because sustainable refurbishment is still in its infancy, and the industry is still determining what works best in any given situation.

By making this information freely available, our aim is to catalyse good practice and thus drive progress in the sustainable upgrading of the UK's existing stock.

Essentially, the tool is database-driven, having an interactive web interface to allow information to be searched and delivered to users.

EST and AECB are providing access to additional data which they are currently gathering; this will be added to the NRC portal as it becomes available.

The portal is aimed at a variety of professionals, including social housing stock managers, architects and small builders.

RESEARCH PROGRAMME

An analysis of similar websites was carried out to inform the site's design, followed by interviews with building professionals to help focus the tool's functionality. This preliminary research was incorporated into a delivery plan produced in conjunction with BRE's IT department. The following tasks were central to delivery:

- define the scope of the web tool's functionality, appearance and logic
- build a database to organise the data
- create a graphical user interface
- collate all existing case study data in a consistent form
- create an information map, to translate simple database entries into detailed, graphical case studies (Figure 2)
- test and refine the tool across multiple iterations.

The site was finalised and launched in late June 2011.

Figure 1: The Refurbishment Portal welcome screen

Figure 2: Case study screen

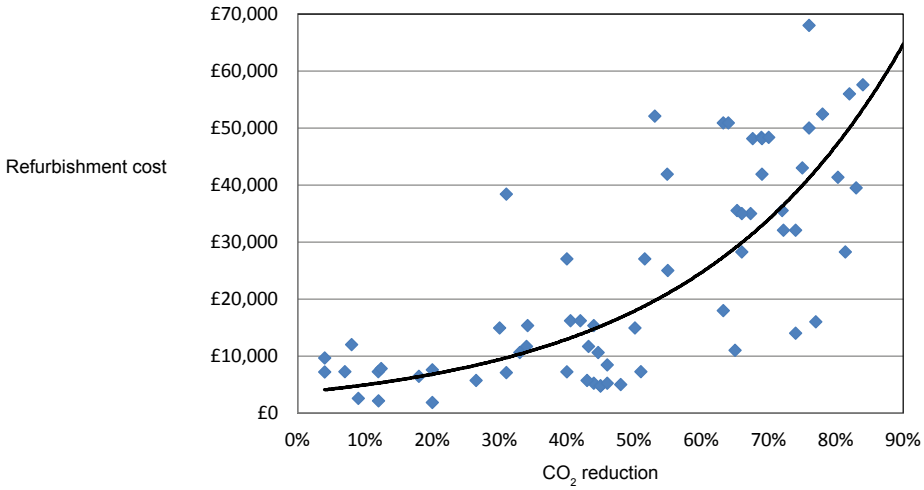


Figure 3: Refurbishment cost against CO_2 reduction

PROJECT OUTCOMES/CONCLUSIONS

The data gathered have allowed a number of conclusions regarding cost and CO_2 savings to be derived; for example, the current data indicate that an 80% reduction in CO_2 should be achievable for an outlay of just under £50 000 (Figure 3).

As further data are added these conclusions can be revisited and updated to track changes within the refurbishment industry.

RESEARCH OUTPUT

The finished web tool can be accessed by visiting the National Refurbishment Centre's website at: www.rethinkingrefurbishment.com/portal/ (see Figure 1).

For further information, contact John O'Brien,
Tel: 01923 664753, Email: obrienj@bre.co.uk

ONLINE TRAINING PROGRAMME

Paul Cartwright

Building Futures, BRE

SUMMARY

Given the financial restraints placed on construction companies in an economic recession, online training in the workplace is an attractive option for improving the skills of the workforce. This project had the objective of developing four online training modules for construction professionals, aiming to provide low cost training material and to help the industry meet its need to train staff in order to achieve the Government's zero-carbon house building targets by 2016.

BACKGROUND

The construction industry is currently facing extraordinary financial challenges and has a pressing need to cut costs. Set against this requirement is the equally pressing need to train staff in order to achieve the Government's house building targets in line with the 2016 zero-carbon agenda.

This situation presents a dilemma for the construction industry since in a time of economic recession, a decrease in staff training and continuing professional development (CPD) may be seen as a legitimate way of reducing costs. However, this will clearly lead to a drop in the quality of UK construction personnel and a weakening of the industry as a whole, at a time when the opposite is required to gain a competitive edge.

During these economic difficulties, there is considerable scope for innovative and cost-effective methods of information delivery to counter a reduction in uptake of training within the construction industry, while simultaneously tackling the endemic problem of poor information dissemination.

Existing collaborative research conducted by the University of Arizona, University of Maryland, GroupSystems Corporation and the Delft University of Technology (Netherlands) indicated that satisfaction levels with this medium of training was high. In addition, feedback from other industries indicated that internet instructional video training is utilised extensively.

The construction sector audience for this type of service is envisaged to be substantial. A similar project, a webinar on the Code for Sustainable Homes produced by BRE for *Building* magazine, was highly successful, having 1400 hits. In the current economic climate, this type of model for information delivery is seen as offering a win-win situation to both training providers and industry stakeholders, by improving staff skills and competitive edge and at the same time reducing costs by making staff training faster, easier and more affordable.

Screenshot from one of the online training modules

RESEARCH PROGRAMME

The objective of this project was to develop four online training modules:

- Making 'The Code' real
- Introduction to microrenewables
- Introduction to site waste management plans
- BREEAM and the benefits of green buildings

The modules were developed over a four-month period that included developing and editing the material, filming on location at BRE and final editing. The modules can be purchased and downloaded from the BRE website.

PROJECT OUTCOMES/CONCLUSIONS

The following outputs were generated from this project:

- four web training modules available to purchase and download from the BRE website
- feedback from the industry on the effectiveness of the web training modules, and also on future pricing and content ideas.

For further information, contact Paul Cartwright, Tel: 01923 664348, Email: cartwrightp@bre.co.uk

PUBLICATIONS PROGRAMME

FOREWORD TO THE BRE TRUST PUBLICATIONS PROGRAMME

The Trust continues to support the preparation of a substantial programme of new and revised publications, and I am pleased to report that no fewer than 38 have been published during the year. As you can see from the summaries which appear on the following pages, these publications cover a diverse range of topics, from guides on good practice through to 'blue sky' reviews and research. This diversity reflects the new challenges facing the built environment and the breadth of BRE's skills and activities that are needed to meet them. The readership is also widening out from BRE's principal traditional audience of construction professionals to managers, scientists and technical specialists across many industries and business sectors. In view of this wide spread of subjects and audience, BRE Trust publications must set out clearly who the intended readership is, and the value that the publications offer them.

I would like to mention one BRE Trust publication from 2011 that exemplifies the best of BRE's publishing tradition: *Ventilation for healthy buildings: reducing the impact of urban air pollution,* pubished as BRE Trust Report FB 30. The subject is clearly of great importance in urban areas, especially as the benefits of good air quality in indoor environments are becoming better understood, and the guidance in this publication presents a coherent and authoritative strategy for taking account in building design of the many factors which influence air quality.

As I have mentioned, BRE is renowned for the breadth of its activities and the expertise of its staff, and for its ability to bring cross-cutting expertise to bear on new problems. This is reflected in the publishing programme, where contributions from different disciplines present new ideas and guidance in a way that can build bridges between different specialists involved in the built environment.

A considerable part of this *BRE Trust Review* focuses on the work of the BRE University Centres of Excellence. A series of five Information Papers on low-impact materials was published in autumn 2011 with authors from BRE and from the Centre at the University of Bath. This collaboration brings a richer perspective to a subject, and it provides researchers in the Centres with an opportunity to present their work to readers who can apply it directly. I look forward to many more such collaborative publications in future.

Developments in electronic delivery of information are getting considerable attention at present, and, while it is in consumer products that the most rapid advances are taking place, we can expect this revolution to spread to business-to-business and technical information over the coming years. We are perhaps just at the threshold of what will be a sea change in the way information is presented and used, but there will still be the need for authoritative presentation of complex technical subjects, and I am confident that BRE publications will continue to be at the forefront, whatever the means by which they are disseminated.

I am sure you will find the brief details of the new publications on the following pages interesting and worthwhile. I repeat the invitation that I made last year that suggestions for topics and approaches for new publications will be welcome.

Hugh Ferguson
Chairman
BRE Trust Publications Committee

BRE TRUST PUBLICATIONS IN 2011

BRE Trust support has made a significant difference to the number and range of publications that are produced by BRE for use by construction professionals and others involved with the built environment. The Trust recognises that these publications are often definitive sources of data, information and knowledge relied on by the construction industry, and that many are referred to in legislation so it is imperative that they are kept up-to-date and relevant.

The titles of the publications approved for funding by the BRE Trust Publications Committee in 2011 are listed in Box 1. All publications are produced by IHS BRE Press and sold through the BRE Bookshop in hard copy or pdf format at www.brebookshop.com.

The following sections provide summaries of the 38 publications that have been published during 2011 whose preparation has been funded by BRE Trust under the BRE Publications Programme funding initiative introduced in 2009. Many other Reports, Digests, Good Building and Repair Guides, and Information Papers are currently being prepared for publication. The range of topics reflects the main areas of work within BRE and BRE Global, and deals with key topics of concern throughout the community of clients and professionals across the built environment.

***Box 1:* Publications approved for funding in 2011 by BRE Trust Publications Committee**

A compendium of UK housing statistics

A review of the financial implications of renewable energy schemes

Assessing the fire performance of existing reinforced concrete flooring systems

Assessing the fire risk of renewable technologies

Benefits of green buildings: annual update 2010

Biodiversity offsetting for developments

Biofuels: how they work and what they deliver

BREEAM and wellbeing (social benefits of sustainable housing)

Building with confidence using crop based materials: an introductory guide

Delivering the S Plan: sustainability at BRE

Emergency evacuation of high-rise buildings

Energy management: a review of best practice

Ensuring good indoor air quality in new and refurbished buildings

Fires in car parks: from research to engineering

Guidance for the selection of flood protection products for buildings

Guidance on the available building envelope credits in environmental certification schemes

Guide to CE marking and the Construction Products Regulation (CPR)

Heat pumps: how they work and what they deliver

International standards and approaches in housing refurbishment

Introduction to building information management (BIM)

Lessons learned from the Rosepark Care Home fire

Low-carbon refurbishment

Maintaining sustainability from building design to building use

Making use of carbon emissions

Matching energy supply and demand: the importance of energy quality

Ninety years of BRE: ninety years of housing change

Penrhiwciber Eco Terrace: targeting the carbon 80 reduction aspiration

Photovoltaics: how they work and what they deliver

Prioritising maintenance and investment in school buildings: a non-technical guide

Radon solutions: 1 Radon sump systems, 2 Positive ventilation systems, 3 Ventilation to suspended timber floors

Real cost of poor housing in Northern Ireland

Reducing the risk of fall hazards in the home

Risks in existing buildings: an overview

Role of animation in building design

Security and fire alarm remote signalling/monitoring

Site layout planning for daylight: site layout for sunlight and solar gain

Solar thermal: how they work and what they deliver

Sound control for homes

Sound insulation between homes

Sustainability strategy for NHS Foundation Trusts

The benefits of a fire engineering approach to refurbishment

The guide to responsible sourcing in construction (Responsible sourcing 'in your hand')

The health–cost benefit of the Decent Homes Programme

The use of Smartwaste to save money, resources and carbon

User-centred design and the support for living and wellbeing

MATERIALS
Alkali-activated binder concretes in construction
IP 4/11, May 2011

Alkali-activated binders have many cost and durability benefits. Their manufacture uses less energy and produces less carbon dioxide than conventional Portland cement. They are based on minimally processed industrial by-products, which significantly reduces the carbon footprint of concretes made from them. BRE-led research has shown that alkali-activated binder concretes can be used on a commercial scale to produce durable concrete products with physical properties that are comparable with or better than those of equivalent Portland cement concrete. This Information Paper provides an introduction to the technology and reviews the benefits of and barriers to wider adoption of these systems. It also presents the results of industrial-scale production trials.

Timber cladding
DG 521, June 2011

Timber cladding is an attractive and sustainable method of providing weather resistance to a building, but has weathering characteristics and a vulnerability to deterioration that need to be anticipated to obtain best performance. This Digest provides information on the design and performance of timber cladding, including material selection and detailing.

Low-impact building materials
IP 14/11–IP 18/11, October 2011

This series of five Information Papers provides a comprehensive, yet accessible, introduction to the low-impact materials of hemp lime, straw bale, unfired clay masonry, cross-laminated timber and natural fibre insulation. The information has been sourced from extensive research by the BRE Centre of Excellence for Innovative Construction Materials, University of Bath, and the expertise of industry professionals with commercial experience of the materials' application. Objective descriptions of the advantages, limitations and typical properties of the various materials are included.

ENERGY

Energy in schools

IP 2/11, March 2011

UK schools cause the emission of 15.6 million tonnes of CO_2 each year, with energy use accounting for approximately 37% of this total. Climate change is high on the UK Government's agenda, so with rising fuel costs and longer school opening hours there are clear benefits if schools actively manage and optimise their operational energy consumption.

This Information Paper is intended to provide school facilities managers, head teachers and caretakers with a simple energy management framework, and to identify energy reducing actions that will save money in the short to medium term.

Ground source heat pumps

IP 3/11, January 2011

An increasingly popular low-carbon technology option is a ground source heat pump (GSHP) used to harness heat (geothermal) energy from the ground. This Information Paper provides an introduction to how GSHPs work and their applications. It also looks at two case studies where GSHPs have been installed.

Biomass energy: Wood fuel for space and water heating

FB 36, August 2011

Biomass is a growing source of energy in the UK. This report investigates the opportunities for using wood fuel for space and water heating in commercial, public and domestic buildings. It outlines the fuels and boiler options and discusses supply chain, planning and regulations, economics and costs. Case studies illustrate 24 applications of biomass energy in a range of housing and commercial, educational and leisure buildings. The report concludes with a review of the case for renewable energy and the drivers that will influence the development of biomass fuel.

Renewable energy technologies: key factors for successful installations

IP 7/11–IP 11/11, September 2011

This series of five Information Papers provides a comprehensive yet accessible introduction to the main renewable energy technologies for buildings and communities covering biomass systems, photovoltaic systems, large-scale low-carbon heating, ground source heat pumps and low-temperature heating, and solar thermal systems. The key characteristics that make a building suitable for each renewable energy system are identified and indicative costs and benefits are given, toegether with sample calculations showing the financial return for a typical household. References to sources of information on legislative requirements for design, installation, commissioning and control, standards, and financial incentives are included.

Lessons learned from community-based microgeneration projects

FB 43, December 2011

This report presents lessons learned from government-funded renewable energy schemes using solar PV and solar thermal technologies, wind turbines, ground source heat pumps and wood-fuelled boilers in schools, colleges and community buildings. Key issues investigated include: community engagement, grant process, installation, specification, operation and performance. The nine case studies provide an overview of the benefits of the installations, the issues surrounding project implementation and how to ensure the system performs in line with the specification.

FIRE AND SECURITY

Fire performance of light steel-framed buildings

IP 6/11, June 2011

This Information Paper discusses the performance in fire of light steel-framed (LSF) buildings constructed from cold-formed steel. It highlights areas where designers and manufacturers may need to look beyond a simple reliance on standard fire test data and consider issues of detailing which may be critical to the performance of the building system in a real fire. Sources of design guidance are identified and the literature on LSF structures in fire is summarised. The paper aims to give designers, insurers and regulators a better understanding of the important considerations when LSF systems are used in the construction of buildings.

Water mist fire protection in offices

FB 34, June 2011

Water mist systems are increasingly being used in the UK to protect buildings, including commercial premises such as hotels, offices and retail units, from fire by limiting the extent of fire damage and and thereby limiting unnecessary wastage of resources, time, salvage and re-instatement operations. However, acceptability of water mist systems is often unproven, the limits of their effectiveness are largely unknown and acceptance criteria are not well established. Successful performance can only be achieved by carefully engineered designs to meet particular applications. This study:

- characterises the mechanisms and factors that govern their effectiveness
- defines a fire test protocol for evaluating systems for commercial offices
- addresses some of the gaps in knowledge.

The report provides research information and data to assist with understanding the mechanisms for successful water mist fire protection systems in offices. It is only with this knowledge and understanding that fixed water mist suppression systems can be assessed and confidence given that they will be effective in protecting property and life.

SUSTAINABILITY

Financing UK carbon reduction projects

FB 31, February 2011

This publication explores the funding of project-based carbon reduction projects in the UK by:

- surveying potential sources of supply and demand for such emission reductions
- examining the regulatory hurdles that need to be overcome to put a funding mechanism in place.

It recommends the creation of a comprehensive reporting framework for carbon reduction projects in the UK that can accommodate the variety of projects and carbon accounting and financial methodologies already in place for funding such projects. The ultimate goal of such a reporting framework will be to create a new asset class, namely project-based carbon reductions in the UK, so that the investment capital required to fund such emission reductions and help the UK to meet its climate change targets can be deployed most effectively across the entire range of voluntary and regulated projects in the UK.

Carbon footprinting and labelling of construction products

IP 5/11, May 2011

The terms 'carbon footprinting' and 'carbon labelling' are in common use in the construction industry, but can be confused and misinterpreted. This Information Paper defines the terms in the context of construction products, and outlines the life-cycle assessment (LCA) principles that underpin them. Associated standards, codes, other schemes and resources are reviewed and the use of carbon footprinting and labelling in the construction industry is discussed, together with relevant organisations, products and construction specifications, and 'whole building' assessment.

This Information Paper is intended to be a resource for architects, constructors, manufacturers, suppliers, academics and regulators so that better-informed decisions can be made about construction products.

Environmental impact of insulation
FB 37, September 2011

Environmental impact of vertical cladding
FB 38, August 2011

Environmental impact of floor finishes: Incorporating The Green Guide ratings for floor finishes
FB 39, November 2011

The first three reports in a series on the environmental impact of materials review how insulation, cladding and floor finishes have been assessed within *The Green Guide to Specification*, including the application of the Environmental Profiles methodology which underlies *The Green Guide* data. The way in which these materials are addressed within building-level environmental assessment schemes such as BREEAM and the Code for Sustainable Homes is also explained.

The reports will give manufacturers and specifiers a general understanding of the significant benefits and impacts of materials over their whole life cycle and help to identify opportunities for improvements to their environmental performance. Each will provide comparable information on cladding, floor finishes, insulation, masonry and concrete, metals, timber and windows to assess their respective environmental impacts.

The report on floor finishes includes a final section which gives the tables of *Green Guide* ratings for floor finishes.

Sustainable refurbishment of the BRE Victorian Terrace
IP 12/11 (Parts 1 and 2 of 3), November 2011

This Information Paper looks at the conversion of the BRE Victorian Terrace from a disused stable block into a number of energy-efficient spaces, including a terraced house, two flats and a presentation room, using the latest processes and materials for building refurbishment.

Part 1 covers the period from the start of the project when the design philosophy was established, through the development of the initial specification to the specification that was in place when the building was scaffolded, sheeted and then stripped back to its shell.

Part 2 reviews the construction process, during which the various products specified were installed. It describes in detail BRE's CALIBRE construction efficiency tool and how it was applied to the project.

Part 3 (not yet published) will cover the lessons learned from the refurbishment.

Assessing the sustainability of office refurbishment with BREEAM
IP 19/11, November 2011

The application of BREEAM to an office fit-out project with a target BREEAM rating of Excellent is illustrated in this Information Paper. The case study describes the fit-out assessment process and how it differs from other forms of BREEAM assessment. It reviews the approach taken by the project team given the challenges that were encountered, and highlights examples of good practice in decision making, project management and the prioritisation of activities. The project demonstrates that an Excellent rating can be a realistic aspiration for many typical refurbishment projects.

DESIGN

LIST (Low Impact Shopfitting Tool) for designing greener shopfitting display equipment

IP 1/11, February 2011

A new web-based tool, Low Impact Shopfitting Tool (LIST), has been developed by BRE in partnership with Leggett & Platt Store Fixtures Europe, FITCH and M&S to enable a sustainable solution to loose shopfitting display equipment. LIST allows retailers, designers and manufacturers to evaluate and compare the environmental impacts of shopfitting display materials and equipment from the initial design stage. It can be used to compare several designs of shopfitting equipment and determine whether one will have a lower environmental impact than another.

Ventilation for healthy buildings: reducing the impact of urban air pollution

FB 30, February 2011

Building designers are increasingly being encouraged to consider sustainable or low-energy ventilation as a primary design option for both new-builds and major refurbishment projects. There is thus much debate about how optimum ventilation may be achieved in urban areas where external contaminants can cause the quality of the incoming air to be unacceptable.

This report provides invaluable practical guidance on developing effective ventilation strategies for reducing the ingress of external pollution into buildings, while at the same time maintaining adequate ventilation.

The cost of poor housing in Wales

FB 32, April 2011

Decent homes are the foundation of people's lives and, as such, a key determinant of health and well-being. Although there is extensive literature on the relationships between poor housing and both physical and mental ill-health, it remains difficult to translate this into action on making housing a priority for public health.

This report summarises research commissioned by Shelter Cymru and BRE Trust to apply a methodology developed to calculate the cost of poor housing in England to the Welsh housing stock. The research found that reducing the worst hazards of poor housing in Wales would save the NHS about £67 million per year.

Dynamic comfort criteria for structures

FB 33, April 2011

The effects of vibration are increasingly important in the design of buildings and building elements. Modern, lighter buildings respond more to imposed vibration, so people are more likely to experience vibration. This report distils the themes and disparate (sometimes conflicting) acceleration comfort criteria associated with building vibration. It considers the Eurocodes, British and ISO Standards, and other sources of information. The status of dynamic testing is discussed, as well as the underlying principles of common test methods. Practical advice is included, and full-scale measurements presented that illustrate the issues.

It is aimed at building designers, consultants, architects and structural engineers.

Airtightness in commercial and public buildings

FB 35, 3rd edition, May 2011

This is the only guide that provides comprehensive practical guidance on airtightness and detailing for commercial and public buildings and other non-domestic buildings. It provides generic examples of frequently occurring air leakage paths and practical guidance on methods and materials suitable for sealing common construction detailing. The guidance also covers managing the airtightness process from design through construction and airtightness compliance testing to handover.

Wind microclimate around buildings

DG 520, May 2011

Tall buildings can deflect high-level wind down towards the ground, producing unpleasant and sometimes dangerous wind conditions in adjoining pedestrian areas. Architects, designers, developers and planners must aim to provide a safe and comfortable wind microclimate in open-air pedestrian areas around buildings.

This Digest brings together the latest information on wind environment around buildings. The general principles of wind flow around buildings and techniques for mitigating unacceptable wind speeds are discussed and advice is given on the methods and criteria for assessing pedestrian wind comfort. The advantages and disadvantages of the different measurement techniques are included. It replaces Digest 390, which has been withdrawn.

LED lighting

FB 40, September 2011

Lighting is one of the largest users of energy in buildings, being responsible for around 20% of electricity use. Good lighting is essential to health, well-being and productivity, but the efficiency of light sources varies widely. To reduce carbon emissions, designers, owners and occupiers are looking at the energy efficiency of lighting.

Light-emitting diodes (LEDs) are a proven technology that offers enormous possibilities for providing highly energy-efficient and good-quality lighting. This BRE Trust Report summarises the current LED market and various advantages of LEDs, and outlines the challenges and barriers to adoption of the technology.

Radon in the workplace

FB 41, 2nd edition, October 2011

This guide to reducing the risk of exposure to radon in the workplace has been thoroughly updated to include lessons learned and changes in legislation since the first edition was published in 1995. It is aimed at managers, maintenance staff and building contractors who need to determine whether a building has a radon problem or to reduce known elevated radon levels. It will help employers comply with radon requirements in the Ionising Radiations Regulations 1999, which were made under the Health and Safety at Work etc. Act 1974.

This highly illustrated guide describes how to identify common construction types and their impact on radon, and explains simply how buildings work and how different ventilation regimes can affect radon levels. Twelve case studies describe different building types together with appropriate solutions.

It has been prepared with assistance from the Health and Safety Executive, Health Protection Agency, Cornwall Council and contractors installing radon remedial measures.

Site layout planning for daylight and sunlight: a guide to good practice

BR 209, 2nd edition, September 2011

The new edition of this highly regarded BRE guide has been fully revised and updated. It gives advice on site layout planning to achieve good sunlighting and daylighting both within buildings and in the open spaces between them. It is widely used during the planning and design stages of building development in the UK and Ireland.

New material in this edition covers dense urban areas, trees and hedges. Intended for use in conjunction with the British Standard Code of Practice for daylighting, guidance is given on:

- site layout for good sunlighting and daylighting
- safeguarding of daylight and sunlight within existing buildings nearby
- protection of daylighting of adjoining land for future development.

A special section deals with passive solar site layout. Advice is given on the sunlighting of gardens and amenity areas. Issues like privacy, enclosure, microclimate, road layout and security are also reviewed.

The appendices contain methods to quantify access to sunlight and daylight within a layout, and a transparent direction finder is included for use with the indicators. Appendix G explains how to use the set of sun-on-ground indicators available separately (see below).

Sun-on-ground indicators

AP 288, October 2011

These indicators are for three different latitudes, and for use with four different scales of plan (1:100, 1:200, 1:500 and 1:1250). The London indicators may be used for southern England and south Wales; the Manchester ones for northern England, north Wales and the southern half of Northern Ireland; and the Edinburgh/Glasgow indicators for Scotland and the northern half of Northern Ireland.

They are designed for use with the second edition of BRE Report *Site layout planning for daylight and sunlight* (BR 209; see above). Appendix G in BR 209 explains how to use the indicators.

Ventilation rate measurement

IP 13/11, October 2011

This Information Paper covers the development of new tracer gases and techniques for measuring ventilation rates in buildings. Effective ventilation of buildings is essential to ensure compliance with regulations relating to energy efficiency, good indoor air quality and the health and well-being of the occupants.

Ventilation rate measurements in buildings are therefore important to inform the design, construction and operation of healthy buildings and to help solve ventilation and indoor air quality-related issues when they arise. However, many tracer gases traditionally used in ventilation rate measurement techniques have now been restricted or prohibited due to their global warming potential. To address this, BRE has identified, tested and validated new, more environmentally friendly ventilation tracer gases and has further developed the perfluorocarbon tracer (PFT) ventilation rate measurement technique to enable inter-zonal flows (ie air flows between different rooms) and the variation in building ventilation rate with time to be quantified.

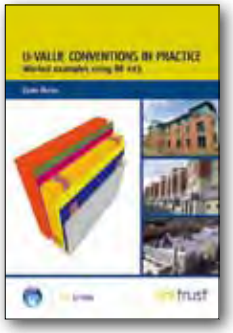
U-value conventions in practice

FB 42, December 2011

This publication will assist designers who need a better understanding of how to calculate U-values and kappa-values for use in calculation tools. It aims to:

- support the implementation of building regulations on conservation of fuel and power and legislation on the energy performance of buildings
- help raise awareness and understanding of U-values (thermal transmittances) and kappa-values (thermal mass values)
- encourage a unified, consistent and up-to-date approach to calculating U-values and kappa-values.

The calculation methods are explained using worked examples for wall, roof and floor designs encompassing the main construction types in BR 443. The examples can be used to support training programmes for practitioners carrying out energy assessments and using U-value calculation software. Information is given about calculating U-values using standard simplified methods.



ABOUT BRE TRUST

BACKGROUND

BRE Trust is a charitable company whose objectives are, through research and education, to advance knowledge, innovation and communication in all matters concerning the built environment for public benefit.

BRE, along with BRE Global Limited and FBE Management Limited, are wholly owned subsidiary companies of the Trust. This ownership structure enables BRE to be held as a national asset on behalf of the construction industry and its clients, independent of specific commercial interests and protects BRE's impartiality and objectivity in research and advice.

Profits made by BRE and by the other subsidiary companies are passed to the Trust and used by it to promote its charitable objectives.

The Trustees meet in Council four times a year to provide strategic direction and to oversee and guide developments of the charity and of its subsidiary companies. The Trustees ensure that the charity pursues its objectives of 'for public benefit' research and education and that the assets owned by the Trust, namely its subsidiary companies, are used in a way that will contribute to the Trust achieving its objectives.

The Trust is the largest UK charity dedicated specifically to research and education in the built environment.

CONSTITUTION

BRE Trust is a company limited by guarantee Company number 3282856 and is registered as a charity in England and Wales (no 1092193) and in Scotland (no SCO39320). It is governed by its articles of association.

Its registered office is Bucknalls Lane, Garston, Watford, Herts WD25 9XX.

TRUSTEES AND OFFICERS OF THE CHARITY

The Trustees serving during 2010 are as given in Box 1.

During 2011 the Trustees delegated the day to day management of the Charity and management of its subsidiary activities to the Executive Chairman of BRE Group, Martin J Wyatt and the Finance Director, Russell Heusch. At the beginning of 2012 Peter Bonfield was appointed CEO of BRE Group and Martin Wyatt was appointed Non-executive Chairman.

***Box 1:* Trustees serving in 2011**

Chairman
Sir Neville Simms FREng

Professor John Burland CBE, FREng, FRS
Mark Clare
Professor Les Clark OBE, FREng
John Carter (appointed 2 March 2011)
Mark Farrar
Hugh Ferguson
Richard Gillies
Dr Liz Goodwin (appointed 2 March 2011)
Richard Haryott FREng
Sir Ken Knight CBE, QFSM (appointed 2 March 2011)
Peter Lobban OBE
Ray Treen (retired July 2011)
James Wates FCIOB, FRSA

Secretary
Russell Heusch

Governance

Trustees are invited to become a Trustee because of the merit of their skills, and because their general expertise would be of benefit to the Trust and represent the wider interests of the built environment.

During 2011, the Council had three committees reporting to it:

- BRE Group Trust Audit Committee
- Research Committee
- Publications Committee.

Management

The Trustees are expected to:

- give strategic direction to the work of the BRE Trust and group companies
- have an input into the strategic business plans of the group companies
- extend the scope of BRE Trust's charitable activities and seek funding

- develop research and education objectives for the charity and prioritise expenditure against such objectives
- act as ambassadors for the work and objectives of the Trust and its group companies
- benchmark the activities and achievements of the Trust and group companies
- ensure the excellence of scientific standards within the BRE group of companies.

All other day-to-day decisions have been delegated to the boards of directors of the subsidiary companies.

Subsidiary companies

The Council of Trustees meets quarterly. The directors of subsidiary companies and senior staff are invited to the meetings to report on operational and business performance.

The activities of the trading subsidiaries are:

- Building Research Establishment Limited provides independent advice and information on building performance, construction and fire safety in the UK
- BRE Global Limited carries out research, testing and certification of materials and products, and certification of personnel, buildings, processes, systems and supply chains
- FBE Management Limited manages research work and carries out consultancy and research for the European Commission and provides technical support for the Construction Products Directive.

BRE TRUST REVIEW 2011

The BRE Trust Review 2011 presents a summary of the year's activities and achievements. The main focus is on short papers from BRE, BRE Global and the five BRE Centres of Excellence, summarising research projects funded by BRE Trust in 2011. The papers demonstrate the breadth and scope of the research that is being supported by the Trust.

BRE TRUST TITLES PUBLISHED BY IHS BRE PRESS

SITE LAYOUT PLANNING FOR DAYLIGHT AND SUNLIGHT
BR 209, 2nd edition, 2011

ENVIRONMENTAL IMPACT OF FLOOR FINISHES
FB 39, 2011

BIOMASS ENERGY
Wood fuel for space and water heating
FB 36, 2011

AIRTIGHTNESS IN COMMERCIAL AND PUBLIC BUILDINGS
FB 35, 3rd edition, 2011

VENTILATION FOR HEALTHY BUILDINGS
Reducing the impact of urban air pollution
FB 30, 2011

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